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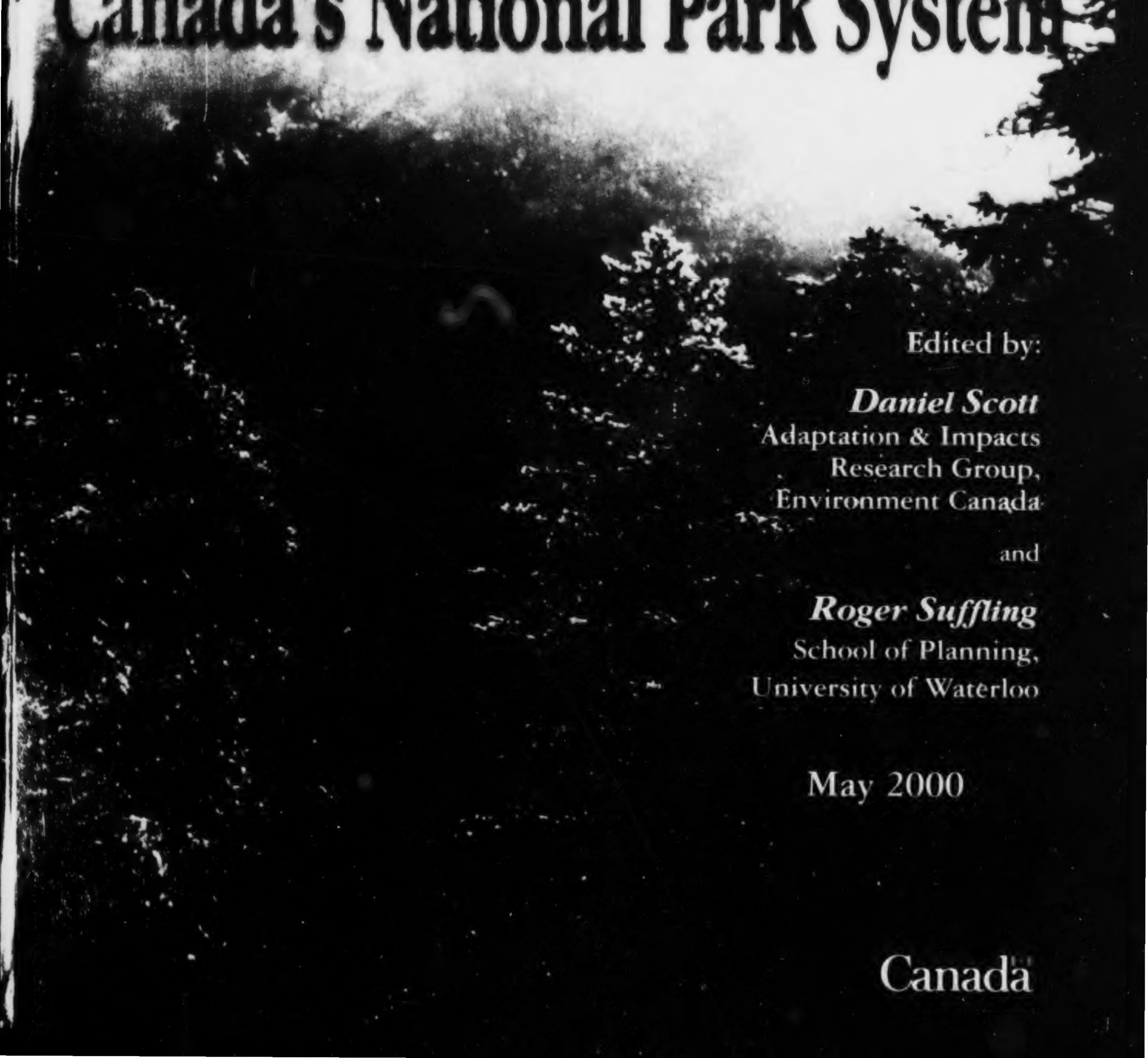
Climate Change and Canada's National Park System



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Canada

Climate change and Canada's national park system: A screening level assessment

Le Changement climatique et le réseau des parcs nationaux du Canada : une évaluation préliminaire

This report was prepared for Parks Canada, Department of Canadian Heritage by the Adaptation & Impacts Research Group, Environment Canada and the Faculty of Environmental Studies, University of Waterloo. The views expressed in the report are those of the study team and do not necessarily represent the opinions of Parks Canada or Environment Canada.

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List of Acronyms

AIRG	Adaptation and Impacts Research Group, Environment Canada
CCCma	Canadian Centre for Climate Modelling and Analysis, Environment Canada
CGCM1	Coupled General Circulation Model 1
CO_2	Carbon-Dioxide
EMAN	Ecological Monitoring and Assessment Network
ENSO	El Nino Southern Oscillation
FWI	Fire Weather Index
GCM	General Circulation Model
GFDL	Geophysical Fluid Dynamic Laboratory, Princeton University
GHG	Greenhouse Gas
GISS	Goddard Institute for Space Studies
HRDC	Human Resources Development Canada
IJC	International Joint Commission
IPCC	Inter-governmental Panel on Climate Change
NCAR	National Center for Atmospheric Research
PDO	Pacific Decadal Oscillation
RCM	Regional Climate Model
UKMO	United Kingdom Meteorological Office
UV	Ultra-Violet
UW	University of Waterloo
WTO	World Tourism Organization

Abstract — Résumé

In collaboration with Parks Canada, a screening level assessment of the impacts of climate change in Canada's system of national parks and national park reserves was completed. Seasonal climate change scenarios, based on four doubled-CO_2 General Circulation Model experiments, were assembled for each national park. Implications for abiotic features, ecosystems, individual species and visitor use of each national park were then examined using national park resource inventories and existing climatological and climate change studies.

A broad range of inter-regional (altered disturbance patterns and successional trajectories, latitudinal and elevational ecotone shifts, extended growing season) and regional (sea-level rise, increased forest fire frequency and severity, diminished sea and lake-ice cover, waning permafrost, altered freshet and seasonal hydrology, wetland loses, retreat of low elevation glaciers, increased insect harassment) climate change impacts were identified as significant for the national parks. Some relatively firm impact projections were possible on the basis of extant research (e.g., the extirpation of polar bears from Wapusk National Park and the loss of some alpine species from mountains of western Cordillera parks and the coastal areas of Forillon and Mingan National Parks). In other instances, significant knowledge gaps precluded precise conclusions (e.g., the impact of climate change on the wintering grounds of Wood Buffalo National Park's

En collaboration avec Parcs Canada, on a procédé à une évaluation préliminaire des répercussions du changement climatique dans le réseau des parcs nationaux et réserves de parcs nationaux du Canada. Pour chaque parc national, on a créé des scénarios de changement climatique saisonnier d'après quatre expériences de modèles selon les saisons de circulation générale avec doublement du CO_2. À l'aide des inventaires des ressources des parcs nationaux ainsi que des études climatologiques et des études sur le changement climatique déjà effectuées, on a examiné, pour chaque parc national, les répercussions des points de vue des caractéristiques abiotiques, des écosystèmes, des diverses espèces et de l'utilisation par les visiteurs.

On a déterminé une gamme étendue d'impacts inter-régionaux (accroissement des perturbations et modification des successions écologiques, changements de latitude et d'altitude des écotones, prolongement de la saison de croissance) et régionaux (élévation du niveau de la mer, augmentation de la fréquence et de la gravité des incendies de forêt, diminution de la couverture des glaces de mer et de lac, retrait du pergélisol, modification des crues nivales et des conditions hydrologiques saisonnières, pertes de terres humides, retrait des glaciers de faible élévation, plus grand nombre d'insectes) du changement climatique jugés importants pour les parcs nationaux. On a pu établir des projections relativement fiables pour certaines répercussions d'après les recherches en cours (p. ex.: la disparition des ours polaires du parc national Wapusk et la disparition de certaines espèces alpines des montagnes de la Cordillère occidentale et du littoral des parcs nationaux Forillon et Mingan).

endangered whooping crane population, the implications of a cooler Labrador current for marine ecosystems in Atlantic national parks). The range of knowledge gaps related to the sensitivity of individual species, park objectives and the national park system plan, represented one of the more important findings of this study.

Recommendations include: 1) reassessment of Canada's national park system plan in the context of climate change, 2) integration of climate change into park selection and design criteria, 3) furthering the connectivity of national parks and other protected areas in Canada and North America, 4) more detailed climate change impact assessment studies in the majority of national parks (including sensitivity analysis of park objectives, threatened species, and historical and archaeological sites), 5) accelerated ecological inventorying and improved monitoring for climate change detection, 6) analysis of potential climate change impacts on park tourism patterns and local economies, 7) improved collaboration with international conservation agencies on the issue of global climate change, and 8) a national roundtable on protected areas and climate change (to co-ordinate impact assessment research and develop adaptation and mitigation strategies).

Dans d'autres cas, on ne peut tirer aucune conclusion précise en raison d'un grave manque de données (p. ex. : les répercussions du changement climatique sur les aires d'hivernage de la population menacée de grues blanches du parc national Wood Buffalo, les répercussions du refroi-dissement du courant du Labrador sur les écosystèmes marins dans les parcs nationaux de l'Atlantique). L'une des grandes constatations de cette étude résidait dans l'importance des lacunes dans les données sur la vulnérabilité des diverses espèces, les objectifs des parcs et le plan du réseau des parcs nationaux.

Les recommandations comprennent notam-ment : 1) une réévaluation du plan du réseau des parcs nationaux dans le contexte du changement climatique, 2) l'intégration du changement climatique dans les critères de choix et de conception des parcs, 3) un renforcement des liens existant entre les parcs nationaux et des autres aires protégées au Canada et en Amérique du Nord, 4) des études d'évaluation plus détaillées du changement climatique dans la majorité des parcs nationaux (y compris des analyses de vulnérabilité des objectifs des parcs, des espèces menacées et des sites historiques et archéologiques), 5) l'accélération de l'inventaire écologique et une meilleure surveillance en vue de la détection du changement climatique, 6) une analyse des impacts potentiels du changement climatique sur le tourisme dans les parcs et sur les économies locales, 7) une meilleure collaboration sur la question du changement climatique avec les agences internationales de conservation, 8) une table ronde nationale sur les aires protégées et le changement climatique (pour coordonner la recherche sur l'évaluation des impacts et mettre au point des stratégies d'adaptation et d'atténuation).

Executive Summary

In 1995, the Inter-governmental Panel on Climate Change (IPCC) declared 'the balance of scientific evidence indicates a discernible human influence on global climate.' Acknowledging some regional exceptions, global climate change is expected to be more pronounced at higher latitudes. The magnitude of human-induced climate change in Canada is projected to be similar to that of the transition from the last glacial to interglacial period, yet take place over a single century. The implications for ecosystem change, and by extension ecological conservation, are considerable.

In Canada's 1997 *The State of the National Parks* report, climate change was identified as a stressor causing significant ecological impacts in seven parks. In order to further our understanding of the implications of climate change for Canada's national parks, a screening level impact assessment was conducted in collaboration with Parks Canada. The specific objectives of the project were to:

1. assemble climate change scenario data from selected General Circulation Models for each of Canada's national parks;
2. complete an initial assessment of how projected climate changes are expected to impact abiotic features, individual species, ecosystems, and visitor activities in each national park, and;
3. identify critical gaps in our understanding of climate change impacts on the national park system.

Seasonal climate change scenarios, based on four doubled-CO_2 General Circulation Model experiments, were assembled for each national park. Maps of the magnitude of climate change projected by the Canadian Centre for Climate Modelling and Analysis (CCCma) – Coupled General Circulation Model I (CGCMI), are presented in Figures 2 to 9. Inter-model comparisons and historical climate information for each national park area are contained in Appendices A to F. The scenarios informed this analysis and more importantly enable park managers and other stakeholders with detailed local knowledge to engage in the process of posing 'what if' questions related to climate change. Stakeholder capacity building is essential to future climate change impact assessments and the successful development and implementation of adaptation strategies.

For the climate change impact assessment component, the 38 National Parks were subdivided into six broad geographic regions (Atlantic, Great Lakes – St. Lawrence, Prairie, Western Cordillera, Pacific, and Arctic) where the range of anticipated climate change impacts would be relatively similar. To ensure consistency across individual park assessments, an impact assessment checklist was developed. The checklist was used to guide the review of park resource inventory and management plans, regional ecosystem literature and relevant climate change studies.

An overview of the potential impacts identified for the national parks in each of the six regions is provided below.

Atlantic Parks

The magnitude of projected climate change in Atlantic Canada is less than the rest of the nation. However, the national parks in this region are likely to experience important climate change related impacts as a result of altered ocean conditions. Climate change related sea-level rise will be exacerbated on Canada's Atlantic coast by continental subsidence. With the possible exception of the Beaufort Sea coastline, projected sea-level rise is likely to have greater ecological consequences in this region than elsewhere in Canada. Shaw *et al.'s* (1998) study of the sensitivity of the Canadian coastal areas to projected sea-level rise, indicated that the likelihood of physical changes in the coastal zones of Kejimkujik, Kouchibouguac and Prince Edward Island National Parks was high. The sensitivity of coastal areas of Cape Breton, Fundy, Gros Morne, and Mingan Archipelago National Parks were rated as moderate. Forillon and Terra Nova were the only Atlantic coastal national parks with low sensitivity.

Increased coastal erosion and salinity changes associated with sea-level rise will have important implications for the marine-terrestrial interface, possibly degrading some key marine, dune, tidal pool, salt marsh, and estuary habitats. For example, the Aspy Bay barrier complex in Cape Breton Highlands National Park is expected to be permanently inundated or become a low marsh environment. Changes to sandspit beaches and tidal flats in Kejimkujik, Kouchibouguac and Prince Edward Island National Parks are of concern as they provide essential habitat for migratory shorebirds, including the endangered piping plover. There is limited nesting habitat outside of these parks for this species and additional stress associated with sea-level rise could further impair breeding success.

The impact of potential changes in ocean currents and water temperatures, and resultant effects for marine system productivity and diversity remains an important uncertainty in this region. Seabird populations will redistribute to reflect projected offshore cooling, with coldwater species, including the black-legged kittiwake (which colonized the Bay of Fundy in the late 1980's) and the razorbill (which recently established a new breeding site in the Bay of Fundy), expanding their breeding range southwards.

The potential for increased storm intensity would mean extreme events would have a larger role in vegetation dynamics in the national parks of this region. A reduced return period would diminish the capacity of vegetation to recover from weather disturbances. When combined with other ecological stresses (e.g., increased disturbance from disease, insect pests and forest fire), existing successional trajectories will be altered. This would favour the transition from boreal to temperate and mixed forests and those species tolerant of disturbed areas.

The potential for less harsh climatic conditions and expanded colonization opportunities for other pioneering species would have important implications for the viability of relict arctic-alpine assemblages in Forillon and Mingan Archipelago National Parks. Conversely, remnants of the Laurentian maple association in Forillon National Park and other assemblages typical of warmer climatic conditions will experience opportunities for expansion.

Great Lakes – St. Lawrence Basin Parks

Changing water conditions in the Great Lakes – St. Lawrence system (in particular water levels and water temperatures) are expected to be one of the most important climate change related impacts in the region. Mean annual water levels are projected to decline to or below historical low water levels, as a result of accelerated evaporation and evapotranspiration in the region. Based on the results of the CCCma – CGCMI 2050 scenario, mean Great Lakes water levels are projected to decline approximately 0.3m to 1.0m and water temperatures increase by 2 to 3°C (Mortsch, 1999).

Lower mean water levels will alter wetland complexes in a number of national parks in the region. On the west-shore of Bruce Peninsula, projected water levels will cause a number of marshes and fens to dry. As marsh complexes dry out more often and are colonized by white cedar, a loss of plant diversity may result. In Point Pelee National Park, the wetland marshes in the Northeast corner of the park may partially dry out, particularly during low water period in late summer and early fall. This could further threaten rare species such as rose swamp mallow and spotted turtles. Nesting sites for the numerous waterfowl Point Pelee is famous for would become more accessible to predators such as raccoon and mink under drier conditions. While new littoral habitats may form eventually, nearshore habitat losses will occur in the short-term, because marginal sand spits will prevent the marsh vegetation from moving lakeward.

Increased Great Lake water temperatures have important implications for reduced frequency of buoyancy-driven water column turnover and reduced water quality. The environmental impacts of this change could be significant, as spring and fall turnovers are important for nutrient distribution and oxygenation of the lakes. Implications for the reef complexes, which skirt the shoreline around the Bruce Peninsula's Cabot Point, remain uncertain. The distribution of fish species in the Great Lakes parks will also change as a result of surface water temperature increases. Species that are at the northern end of their range, such as the centrarchid (black bass and sunfish) and percichthyid (white bass and white perch), are expected to expand. Walleye and yellow perch may retreat to areas of colder water. In La Mauricie National Park, the arctic char is at the southern end of its range and is thus likely to be especially susceptible to warmer conditions. The widespread extirpation of stream salmonids in the park has also been projected.

The coastal and island nature of the five national parks in Ontario will reduce the impact of increased forest fire frequency and intensity projected for much of northern and eastern Ontario (the fire weather index is predicted to increase 1.5–2 times under doubled-CO_2 conditions – Thompson *et al.*, 1998). Nonetheless, the seasonal forest fire severity rating is projected to increase in four of Ontario's five national parks. The increase in fire disturbance (especially when combined with projected increases in disease and insect disturbance) will shift forest age class distributions down. This change would be detrimental to mature forest species (such as moose and fishers), while providing increased habitat for the bear, beaver, deer (where applicable) and other species that benefit from early successional habitat resulting from increased forest fire frequency. This is of particular importance to Pukaskwa National Park due to its program to protect the woodland caribou.

A warmer climate combined with enhanced disturbance patterns would increase the susceptibility of natural systems to the expansion of non-native invasive species. Point Pelee already has more exotic species than any other Canadian National Park (247 plant and animal species) and will likely see the introduction of new dry land Carolinian species as they shift northward. Seventy plant species within La Mauricie National Park are considered rare and of special interest and the impact of climate change on the range of these plants will be of particular concern to that park's conservation efforts.

Prairies Parks

With the exception of the Arctic Region, national parks in the Prairie provinces are projected to experience the greatest temperature increase under doubled–CO_2 conditions. Increases in temperature will cause an increase in evaporation rates, lower soil moisture levels, and more incidents of drought. The implications of projected precipitation changes (greater spring runoff due to increased winter precipitation and lower summer flows) for seasonal hydrology are also important in the Prairies. With lower summer precipitation anticipated, summer base stream flows in several Prairie parks may decrease and some permanent streams may become intermittent under double-CO_2 conditions. Water temperatures in streams and rivers are also expected to increase, resulting in less dissolved oxygen in aquatic systems. Shuter *et al.* (1998) found that higher temperatures and low water levels could cause many fish species to shift northward by approximately 150 km for every 1°C rise in average temperature.

Hydrologic changes will also have an impact on wetlands and waterfowl. Waterfowl breeding in many of the Prairie parks is dependent on temperatures during the month of May and precipitation during the spring season. Changes in these two variables will cause a shift in breeding patterns and species composition within the region. Prince Albert National Park is home to the second largest pelican breeding area in Canada. Located on Heron Island in Lavalee Lake, the colony is the only fully protected nesting colony of American white pelicans in Canada. Lower water levels in the lake may expose nesting

sites to predators. The Peace-Athabasca Delta, one of the word's largest inland deltas and a wetland of global significance, lies within Wood Buffalo National Park. Wetland dynamics will be of utmost importance for the protection of the only known breeding ground of the endangered whooping crane.

Several Prairie region parks are located along ecotones between grassland and forest and between forest and tundra, and the magnitude of projected climate change in the region suggests these parks are likely to be more susceptible to ecological shifts than parks in most other regions. Analysis of Lenihan and Neilson's (1995) study of climate change and forest formation type, indicated all the national parks in the Prairie region would undergo a shift to another forest formation type. Boreal forests in the Prairie region will be negatively impacted, shifting as much as 100 to 700km to the north (perhaps out of Prince Albert National Park). Boreal species would eventually be displaced by more southern forest species and grasslands, which have a higher tolerance of temperature increases and drought conditions. Wood Buffalo National Park is at a transition zone between the boreal and taiga biomes, the type and rate of soil formation may hinder the northern migration of boreal forests as climate conditions change (i.e., soil formation would lag behind the rapid climate change projected in the region).

Increased drought conditions will increase the frequency and intensity of forest fires in the northern sectors of the region. Doubled-CO_2 scenarios indicate the fire weather index (FWI) ratio will increase by a factor of 1.0 in the Elk Island National Park region, 1.5 to 2.0 times in the Riding Mountain National Park Region, and over 2.4 times for most of the summer in the Wood Buffalo National Park region (Thompson *et al.*, 1998). Fire disturbance will shift forest age class distributions down. This will affect species that depend on mature forests. Increased fire disturbance would contribute to greater forest habitat fragmentation, hastening the expansion of grasslands in the Prairie region parks.

Biome shifts and the loss of old-growth forests will decrease the likelihood of survival for many wildlife species dependent on the boreal forest and a gradual change toward species favouring grasslands and temperate forest ecosystems. Animal species favoured by grasslands, such as elk, bison, western meadowlark and badger, will be more likely to adapt to changing conditions. Bears may also benefit as they thrive in the diverse forest landscapes that result from fires. If the preferred coniferous forest habitat of the Prince Albert National Park woodland caribou eventually retreats beyond the borders of the park, they may be extirpated from the park. Grasslands National Park is home to several rare and endangered species including the burrowing owl and one of the few remaining black-tailed prairie dog colonies in Canada. Although expanded grasslands in other protected areas may benefit these species, further research is needed to determine the impacts of climate change on these populations (i.e., in one scenario Rizzo and Wiken's, 1992 model predicts the emergence of a semi-arid desert in this region).

Western Cordillera Parks

While not likely to experience the magnitude of latitudinal species shifts in some other regions, parks in the Cordillera region will be the most susceptible to elevational shifts. Banff National Park alone contains forty-one plant species that reach their range limits in the park and will therefore be particularly sensitive to climate change. Projected changes in temperature and precipitation are conducive to the expansion of subalpine and montane zones. The subalpine and mountain meadow ecosystems will increase in size, with their boundaries increasing in altitude. This will be facilitated by increased avalanche activity clearing paths along the alpine slopes. A mean annual temperature increase of only 3°C is predicted to result in an upward shift of the alpine-subalpine ecotone by 500 to 600 metres. This would decrease the size of the alpine ecosystem and lead to the extirpation of some alpine species that are unable to adapt. These changes are likely to result in a net loss of biodiversity in the Western Cordillera national parks as mountain peaks are denuded of some high altitude plant species. The effect of CO_2 enrichment is postulated to be greater for high-altitude plants and therefore of possible significance for mountain ecosystems. Understanding of this phenomena and interactions with other climate change related impacts remains limited. Increased summer temperatures and drier summer conditions would benefit the only Douglas fir/ponderosa pine/wheatgrass ecosystem in the Canadian Rocky Mountains, located at the Dry Gulch-Stoddart Creek area of Kootenay National Park.

Mean winter temperatures would remain below freezing in all GCM scenarios, thus additional winter precipitation will likely increase the snow pack in all of the Western Cordillera national parks. An increased snow pack has several implications for the parks. The migration of animals through the park will be impaired by a greater snow pack. Mountain valleys, with shallower snow packs, are the wintering zones for ungulate herds. In response to deeper snow, ungulates may migrate further down valley to find food throughout the winter. The need for large mammals to escape a deeper snow pack by moving into the lower elevations has implications for animal mortality in some parks. For example, the Trans Canada Highway and the Canadian Pacific Railway (CPR) transect Banff National Park and this transportation corridor plays a significant role in wildlife mortality. Although a fence has been erected along the length of the highway and animal crossings (over and under passes) added, the CPR remains an issue.

The magnitude and frequency of avalanches is also expected to increase. The projected increase in winter temperatures is expected to lead to unstable layers in the snow pack, triggering increased avalanche activity throughout the winter. The increased avalanche activity will cut longer and wider meadows in sub-alpine forests, as well as dump more debris into stream courses. The open meadows created by avalanches will provide increased habitat for some wildlife, such as the hoary marmot. However, an increase in avalanche activity is also a human hazard, both in the backcountry, developed areas and transportation corridors. Emergency costs may increase as a result.

Warmer spring and fall temperatures will extend the melting season of glaciers by at least one month in the southern Rocky Mountains. Lower elevation glaciers, such as the Peyto in Banff National Park, are expected to retreat rapidly as a result of projected climate warming. Glaciers less than 100m thick could disappear over the next 20 years (Brugman *et al.*, 1997). Glaciers with higher accumulation zones, such as the Columbia Icefields in Jasper National Park, will be less affected and may even advance slowly with projected increases in winter snowfall.

Altered hydrology from enhanced glacial melting and altered spring freshet (June instead of May) would have implications for river ecology and recreation. Accelerated glacial retreat would augment summer runoff until the glaciers have been largely depleted. Blais *et al.* (1998) observed high concentrations of persistent organochlorine compounds in glacial ice and snow in the mountain ranges of Western Canada (concentrations were elevated 10 to 100-fold between 770 and 3100m elevation). These pollutants have accumulated over decades via long-range air transport. A rapid glacial melt may release these trapped pollutants in sufficient quantities to be of concern for downstream aquatic ecosystems. The alpine lakes are typically oligotrophic (Achuff and Pengelly, 1986) with low temperatures and short growing seasons. Increased mean annual temperature would slightly increase lake temperatures. However, it is unlikely that these glacial-fed water bodies will warm sufficiently to change growth patterns of aquatic species. The warmer temperature throughout the year is also expected to increase the ice-free season of alpine, subalpine and montane lakes. The Vermillion Lakes Wetland Area of Banff National Park is highly sensitive to water level changes and thus could be adversely effected by altered seasonal hydrology.

Forest fire, disease outbreak and insect infestations are projected to increase throughout the Western Cordillera parks. The ecological consequences of these intensified forest disturbances in the complex topography of the region are still largely uncertain.

Pacific Parks

As in the Atlantic Region, the national parks of the Pacific Region are projected to experience a lesser degree of climatic change than the continental interior. In contrast to the Atlantic coast, isostatic rebound on the Pacific coast will offset sea-level rise to some extent. The coastlines of the Pacific region national parks have a low sensitivity to physical change from sea-level rise (Shaw *et al.*, 1998a). The combination of slight sea-level rise and greater storm intensity could nevertheless alter the level and salinity of groundwater as well as the balance between fresh and saline estuary habitat in some coastal areas. This could have implications for seabirds, shellfish and other estuary dwellers.

The projected 3.5°C increase in sea surface temperatures in the Northeast Pacific over the next 50 years may have the most important ecological impact on the marine, coastal and riverine ecosystems of the region's national parks (including reduced nutrient upwelling,

spawning, migrations and the introduction of southerly species). An increase in sea temperature should lead to an increase in the frequency and distribution of red tide blooms. Warmer water would also support higher populations of southern fish species such as mackerel and albacore tuna, which prey on and compete heavily with salmon populations. It is unclear how kelp beds will be impacted by changes in temperature; however they will likely be able to adapt to a slowly rising sea-level.

Like national parks of the Western Cordillera, Pacific parks will be susceptible to elevational shifts in habitat. Although confined to the higher elevations of the Queen Charlotte Mountain Ranges at the northern edge of the Gwaii Haanas National Park Reserve, the montane spruce and alpine tundra ecoregions could be significantly effected by projected temperature and precipitation changes. The Montane Spruce ecoregion will likely shift in elevation in response to changing snow levels and growing season on the upper boundary of the zone; while coastal western hemlock may gradually replace montane spruce on the lower boundary. Alpine tundra is particularly threatened by conditions favouring the encroachment of species from the montane spruce zone. Depending on the size of remaining alpine habitat, some alpine species may be extirpated from the park. In Kluane National Park Reserve, it is likely that more southerly species will migrate into the park as conditions become milder. Invasive species with aggressive colonization strategies would be favoured in a disturbed ecological state. Changes in elevational distributions are also likely, with montane, subalpine and alpine communities potentially shifting upslope. If the treeline expands, habitat for subalpine species may be reduced, resulting in extirpation of some species. In Pacific Rim National Park Reserve, the sitka spruce forest may extend further inland as this community is more tolerant of mesic conditions. There may also be a shift to Douglas fir communities as conditions shift to drier, warmer summers. Because these trees live for hundreds of years, the effects of species shifts will likely be visible for centuries.

The anticipated increase in runoff throughout the year could open up new areas of rearing and wintering habitat in streams that have not historically supported a salmon run. This might mitigate the expansion of southerly species to some extent. The impact of earlier peak flows (May instead of June) throughout the region for salmon migration and spawning is uncertain. Since salmon form such an integral link in the terrestrial food chain during their migration, other species such as bear and bald eagle would be adversely effected by reduced salmon populations.

In contrast to the lower elevation glaciers in southern British Columbia, glaciers in Kluane National Park Reserve have been advancing. This trend is projected to continue despite higher year round temperatures. Winter snowfall is projected to increase and accumulation zones are high enough for the continued advance of glaciers. In Kluane National Park, increased glacial discharge and precipitation levels will likely increase the levels of several important lakes. This will decrease the size of Bates Lake Island, a nesting colony for arctic terns, mew gulls and herring gulls. The nesting trumpeter swan

population at the confluence of Alder and Fraser Creeks could also be displaced by increased water levels.

Arctic Parks

The magnitude of projected climate change is greatest in the Arctic national parks. Considering environmental conditions (temperature, light, growing season) are close to the limits for life in the Arctic, ecosystems in this region are likely to be the most sensitive to global climate change.

The magnitude of projected seasonal temperature increase in this region is partially the result of diminished reflective capacity from reduced periods of snow and ice cover. These changes also have significant ecological implications. Projected temperature increases would extend the growing season and allow the invasion of more southerly species. The herbaceous bioclimatic zone of Quttinirpaaq (formerly Ellesmere Island) National Park may see increased colonization of tundra plants as warmer air temperatures combine with increased ground moisture and deeper active permafrost layer (permafrost boundaries may move northwards by as much as 500km) to give more favourable growing conditions. The barren lands of Aulavik National Park may also become increasingly populated by tundra plant species. Further south, Tukut Nogait National Park contains rare plant species from Beringia that will be subject to changes under a warmed climate. Range expansions can be expected for plants that thrive in wet conditions, such as sedges, willows, and cottongrass. There may be increased invasion of boreal species from the south and slow growing tundra vegetation (e.g., lichens, cushion plants) may not be able to compete and be forced to higher elevations. The tree line is projected to advance northward by 200 to 300 kilometres throughout the region. As the transition area between low arctic tundra to subarctic woodlands, Ivvavik and Vuntut National Parks are likely to see an expansion in forested areas. At the southern margins of this region, plant communities in Nahanni National Park will shift elevationally in addition to latitudinal change. The lowland and montane zones will expand upslope, with the subalpine and alpine tundra zones facing a reduction in size. Black spruce stands are expected to be at least partially displaced by mixed-wood forests, balsam fir, white pine and white spruce characteristic of a cool temperate ecoclimatic province.

These changes in vegetation distribution and abundance will have important effects on park wildlife. Lemmings are keystone species in Aulavik National Park because many birds of prey and other predators rely on them. Kerr and Packer (1998) project severe range reductions for lemmings in the face of increased warming, which will have substantial consequences for the arctic ecology of this park. The muskox population in Tukut Nogait National Park is particularly at risk from vegetation shifts, since they are at the southern edge of their range. Summer forage availability might increase with more lush vegetation, however populations would suffer if winter conditions lead to a deeper snow pack with more ice layers. Furthermore, muskoxen may be extirpated from the park

if taiga vegetation becomes overly abundant. Changes in caribou and muskoxen populations will undoubtedly lead to changes in predator populations, such as grizzly bears, wolverines, and wolves. The moose population of Vuntut National Park may benefit from climate change if wintering habitats of high cover and food availability, such as deciduous shrub areas, become increasingly available with the invasion of taiga vegetation. Grizzly bears would benefit from increased shrub cover and increases in moose populations, so long as the habitat does not become dominated by larger tree species. Conversely, grizzlies would be negatively affected if caribou migration routes change under a new hydrological regime and/or if caribou populations suffer from changes occurring in their calving and overwintering grounds. In Nahanni National Park, the up-slope shift of forest communities may decrease the open habitat for grizzly bear and Dall's sheep, but increases in avalanches may provide more subalpine meadow habitat. Wolves may benefit from the increased habitat for prey populations, such as white-tailed and mule deer.

The reduction of sea ice also has important implications for several Arctic parks. With increased fall, winter, and spring temperatures Arctic seas are expected to have extended open water seasons (up to 90 days longer in the Beaufort Sea) and decreased ice thickness. This will have substantial impacts on sea mammals. Some sea mammals (e.g., whales) may benefit if sea ice decreases, however species which depend on sea ice and snow conditions for shelter and rearing young (such as polar bears, ringed seals, arctic foxes and arctic hares) will be adversely impacted by a warmer climate. Any shifts in prey populations will have an effect on large predators such as arctic wolves, polar bears as well as scavengers like foxes. Changes in the extent and type of ice cover will reduce the ability of polar bears to access prey, forcing them to move north or to stay inland longer, which would increase nutritional stress levels and lower reproductive success. Since the polar bear population at Wapusk National Park is already near the southern range limit, it is expected that they will be extirpated from the park. Decreased winter sea ice formation might limit inter-island migration and genetic exchange among the caribou herds of the arctic islands, which will inevitably result in a depleted genetic stock of the Peary caribou of Banks Island

Increased snow depth and/or the presence of ice layers in the snow would lead to increased energy expenditure in foraging for caribou and muskoxen. The net result may be lower nutritional levels and reproductive success. In addition, caribou are sensitive to insect harassment, which is predicted to increase in season length and severity under warmer conditions. Russell (1993) predicted the combined stress in Quttinirpaaq National Park would result in parturition rate declines of 40% to complete reproductive failure in worst case scenario. Changes in wildlife populations and migration routes will have considerable impacts on the traditional cultures of Canada's arctic.

Sea-level rise will have varied effects on Arctic region parks. Isostatic rebound in the Quttinirpaaq National Park area will largely negate projected sea-level rise, while subsidence in the Auyuittuq and Ivvavik National Parks will exacerbate sea-level rise (with a net 0.5 to 1 metre rise in sea-level over the next 100 years). The coastline of Ivvavik National Park was rated as moderately to highly sensitive to physical impacts from rising sea-levels (Shaw *et al.*, 1998a). Much of the western Canadian population of snow geese and sea ducks that use coastal areas as staging grounds will be forced elsewhere if climate change results in reduced coastal habitat and/or increased shoreline erosion. The shoreline of Aulavik National Park was rated as moderately sensitivity, with the most sensitive features being beaches in front of bluffs of unconsolidated sediment, deltas and estuaries. The sensitivity of the rocky shorelines of Quttinirpaaq and Auyuittuq National Parks is low.

Most of the land in Vuntut National Park was unglaciated during the last ice age. Consequently, Vuntut National Park has been referred to as an area of 'unequalled value for paleoecological research' (Parks Canada, 1995). Unfortunately, the fossilized remains of prehistoric culture could be adversely effected by changes in hydrology and vegetation. If peatlands disappear, these fossilized remains will be exposed to damaging oxidizing agents and will decompose. In addition, increased erosion along the Old Crow River may lead to the elimination of many sites of archaeological interest identified in park inventories.

Conclusions

Climate change will be a dominant factor in ecological protection during the twenty-first century and represents an unprecedented challenge for Parks Canada. Climate change simultaneously represents a threat and opportunity to different species and ecological communities within the national parks system. The relative significance of climate change for protected areas in each region of Canada and more so, individual parks will therefore differ. As individual species respond to climate change, current ecological communities will begin to disassemble and 're-sort' into new assemblages. The dynamic biogeography brought about by global climate change will effectively alter the 'rules' of ecological conservation. Accordingly, the strategic role of Parks Canada in an era of climate change requires much analysis and deliberation.

Though not the primary focus of this study, it is evident that climate change will also alter recreational opportunities and visitation patterns within the national parks. Canada's system of national parks represents a major tourism resource. Tourism expenditures attributable to national parks visits (approximately $1.2 billion in 1994/95 - Parks Canada, 1998a) have a significant effect on the economies of many communities. To what extent changes to the character of the natural landscape, wildlife, cultural features, or recreational opportunities in national parks would diminish the appeal of certain parks to visitors requires further study.

The substantial knowledge gaps identified throughout this analysis point to the need for a program of research to examine the ecological and tourism implications of climate change in the national parks. Some initial research directions include:

- A comprehensive re-assessment of Canada's national parks system plan in the context of climate change;
- More detailed impact assessment at the individual park level, explicitly examining the implications of climate change for each park's management objectives and 'desirable state.' Assessments of park management plans might include the following elements: identification of historical and archaeological sites at risk from climate change impacts, analysis of the sensitivity of Canada's species at risk to climate change, examination of how climate change might effect the invasibility of park habitats, and how current management practices may influence evolutionary trajectories;
- An analysis of climate change implications for national park-based tourism in Canada, including: how climate change would effect the conditions and experience of various recreation activities (e.g., season length, access and safety, infrastructure), the compatibility of recreational changes with park objectives, the economic implications of altered tourism patterns for Parks Canada and surrounding communities.

Parks Canada should also take a leadership role in initiating a national (or bi-national) climate change roundtable (composed of representatives from protected area agencies, the scientific community and other stakeholder groups) on protected areas and climate change. This working group would identify key research needs and examine the range of adaptation pathways (e.g., fire and invasives management, park selection and design criteria) and greenhouse gas mitigation options (e.g., new fleet efficiency standards, piloting new renewable energy technologies, and carbon sequestration through landscape management and restoration).

Climate change has the potential to undermine decades of notable conservation efforts in Canada and poses a potential threat to this intergenerational heritage trust. It is hoped this assessment will inform readers of the challenges climate change poses for ecological conservation, furthers the task of integrating climate change into Parks Canada strategic planning and policy formulation, and inspires broader visioning of the role of protected areas in an era of human-induced climate change.

Synthèse

En 1995, le Groupe Intergovernmentale d'Experts en l'Evolution du Climat (GIEC) a déclaré que « la prépondérance de la preuve indique qu'il existe une influence humaine évidente sur le climat du globe ». Exception faite de certaines régions, le changement climatique à l'échelle mondiale devrait s'accentuer sous les latitudes supérieures. On s'attend à ce que le changement climatique d'origine anthropique au Canada atteigne une ampleur similaire à celle de la transition de la dernière époque glaciaire à l'époque interglaciaire, le tout concentré sur un siècle. Les répercussions au chapitre du changement des écosystèmes et, de ce fait, de la conservation de l'environnement, sont considérables.

Selon le *Rapport sur l'état des parcs de 1997*, le changement climatique est un agresseur ayant des répercussions sur l'environnement dans sept parcs. Dans le but de mieux comprendre les répercussions du changement climatique sur les parcs nationaux au Canada, on a procédé à une évaluation préliminaire en collaboration avec Parcs Canada. Le projet visait précisément à :

1. réunir des données de scénarios sur le changement climatique à partir de certains modèles précis de circulation générale pour chacun des parcs nationaux du Canada;
2. procéder à une évaluation initiale de la manière dont les changements climatiques prévus se répercuteront sur les aspects abiotiques, les espèces individuelles, les écosystèmes ainsi que sur les activités des visiteurs dans chacun des parcs nationaux;
3. déterminer les lacunes critiques dans notre compréhension des répercussions du changement climatique sur le réseau de parcs nationaux.

Pour chaque parc national, on a créé des scénarios de changement climatique selon les saisons d'après quatre expériences de modèles de circulation générale (MCG) avec doublement du CO_2. Les figures 2 à 9 présentent les cartes démontrant l'ampleur du changement climatique prévu par le Centre canadien de modélisation et d'analyse climatiques (CCMAC) – Modèle couplé de circulation générale I (MCCGI). Les Annexes A à F contiennent des comparaisons entre les modèles ainsi que des données historiques pour chaque région de parc national. Les scénarios ont éclairé cette analyse et, surtout, ont fourni aux gestionnaires de parcs et à d'autres intervenants des données à l'échelon local pour aborder l'étape de formulation d'hypothèses au sujet du changement climatique. Pour les futures évaluations des répercussions du changement climatique et pour pouvoir développer et mettre en application des stratégies d'adaptation, il est essentiel de renforcer les capacités des intervenants.

Pour la composante de l'évaluation des répercussions du changement climatique, on a réparti les 38 parcs nationaux en six grandes régions géographiques (Atlantique, Grands Lacs – Saint-Laurent, Prairies, Cordillère, Pacifique et Arctique) dans lesquelles le

changement climatique aurait une gamme de répercussions assez similaires. Dans le but d'assurer l'uniformité entre les diverses évaluations des parcs, on a mis au point une liste de vérification de l'évaluation des répercussions. On a utilisé cette liste pour guider l'examen de l'inventaire des ressources et des plans de gestion des parcs, des documents publiés sur les écosystèmes régionaux et des études pertinentes sur le changement climatique.

On trouvera ci-dessous un aperçu des répercussions potentielles pour les parcs nationaux dans chacune des six régions.

Parcs de l'Atlantique

Le changement climatique prévu dans le Canada Atlantique est moins important qu'ailleurs au pays. Il se pourrait toutefois que les parcs nationaux de cette région connaissent des répercussions importantes en raison du changement dans les conditions de l'océan. À l'élévation du niveau de la mer lié au changement climatique viendra s'ajouter la subsidence du continent sur la côte Atlantique. À l'exception peut-être de la côte de la mer de Beaufort, l'élévation prévue du niveau de la mer aura tout probablement des conséquences écologiques plus grandes dans cette région qu'ailleurs au Canada. Selon l'étude de Shaw *et al.* (1998) sur la vulnérabilité des régions côtières canadiennes à l'élévation du niveau de la mer, les probabilités de changements physiques sur le littoral des parcs nationaux de Kejimkujik, de Kouchibouguac et de l'Île-du-Prince-Édouard sont élevées. La vulnérabilité des régions du littoral des parcs nationaux du Cape-Breton, de Fundy, de Gros Morne et de l'archipel de Mingan a été évaluée comme modérée. Sur la côte Atlantique, seuls les parcs nationaux Forillon et Terra Nova ont été jugés peu vulnérables.

L'accroissement de l'érosion côtière et les changements de salinité associés à l'élévation du niveau de la mer auront d'importantes répercussions à l'interface mer-continent, peut-être par la détérioration de certains habitats clés du milieu marin, des dunes, des cuvettes de marée, des marais salés et des estuaires. Par exemple, on prévoit que le complexe de la barrière de la baie Aspy, dans le parc national des Hautes-Terres-du-Cap-Breton, sera complètement inondé ou deviendra un marais bas. Les changements aux flèches littorales et aux battures dans les parcs nationaux de Kejimkujik, de Kouchibouguac et de l'Île-du-Prince-Édouard sont préoccupants puisque ces endroits constituent un habitat essentiel pour les oiseaux de rivage migrateurs, y compris le pluvier siffleur, une espèce menacée. À l'extérieur de ces parcs, les habitats de nidification sont limités pour cette espèce et le stress supplémentaire associé à l'élévation du niveau de la mer pourrait avoir d'autres répercussions négatives sur la reproduction de ces oiseaux.

L'impact de changements possibles dans les courants marins et la température des eaux ainsi que les effets qui en découlent sur la productivité et la diversité du réseau marin demeure une incertitude importante dans cette région. Les populations d'oiseaux de mer

adopteront une nouvelle répartition reflétant le refroidissement prévu au large; les espèces des eaux froides, notamment la mouette tridactyle (présente dans la baie de Fundy depuis la fin des années 1980) et le petit pingouin (qui a récemment établi un nouveau lieu de nidification dans la baie de Fundy), vont agrandir leur aire de reproduction vers le sud.

En raison des risques d'accroissement de l'intensité des orages, les événements extrêmes joueraient un rôle plus large dans la dynamique de la végétation dans les parcs nationaux de cette région. Une périodicité de retour réduite aurait pour effet de réduire la capacité de la végétation de récupérer après les perturbations atmosphériques. Les successions écologiques existantes, soumises de plus à d'autres agressions écologiques (effet accru des maladies, des insectes et des parasites ainsi que des incendies de forêt), seront modifiées. Cela favoriserait la transition des forêts boréales aux forêts tempérées et mélangées et serait bénéfique pour les espèces capables de survivre dans les aires pertrubées.

La possibilité de conditions climatiques moins rigoureuses et d'extension du potentiel de colonisation par des espèces pionnières auraient d'importantes répercussions sur la viabilité des assemblages arctiques-alpins dans les parcs nationaux de Forillon et de l'archipel de Mingan. Réciproquement, les vestiges de l'association de l'érable laurentien dans le parc national Forillon et d'autres assemblages typiques de conditions climatiques plus chaudes auront l'occasion de se propager.

Parcs des Grands Lacs et du bassin du Saint-Laurent

Les conditions changeantes des eaux dans les Grands Lacs et le bassin du Saint-Laurent (le niveau et la température de l'eau en particulier) devraient être l'un des plus importants impacts liés au changement climatique dans cette région. On prévoit que les moyennes annuelles des niveaux d'eau chuteront à des valeurs égales ou inférieures à celle des niveaux les plus bas jamais atteints par suite de l'accélération de l'évaporation et de l'évapotranspiration dans cette région. D'après les résultats du scénario 2050 du CCMAC – MCCGI, le niveau moyen des eaux devrait s'abaisser d'environ 0,3 m à 1,0 m et la température grimper de 2 à 3 °C (Mortsch, 1999).

Une baisse des niveaux d'eau moyens se répercutera sur les complexes des terres humides dans un certain nombre de parcs nationaux de la région. Sur la rive ouest de la péninsule Bruce, les niveaux d'eau prévus entraîneront l'assèchement d'un certain nombre de marais et de fens. Si les complexes de marais s'assèchent plus souvent et sont colonisés par le thuya occidental, on pourrait constater une perte au niveau de la diversité des végétaux. Dans le parc national de la Pointe-Pelée, les marais de terres humides du coin nord-est du parc pourraient s'assécher en partie, particulièrement lorsque le niveau de l'eau est faible, à la fin de l'été et en automne. Cela pourrait en outre menacer des espèces rares comme la ketmie des marais et la tortue ponctuée. Dans des conditions plus sèches, des prédateurs comme le raton laveur et le vison auraient plus facilement accès aux aires

de nidification de nombreuses espèces de sauvagine auxquelles la Pointe-Pelée doit sa réputation. Bien que de nouveaux habitats de littoral puissent se créer, on pourrait constater des pertes d'habitats à proximité du rivage à moyen terme parce que les cordons sablonneux empêcheraient la végétation des marais de se propager vers le lac.

L'augmentation de la température des Grands Lacs a des répercussions négatives sur la fréquence de renouvellement de la colonne d'eau sous l'effet de la flottabilité et sur la qualité de l'eau. Ce changement pourrait avoir des répercussions importantes sur l'environnement, étant donné que le renouvellement printanier et automnal des eaux revêt une grande importance pour la répartition des nutriants et l'oxygénation des lacs. Les implications pour les complexes de récifs biohermes, qui bordent le rivage autour de la pointe Cabot de la péninsule Bruce, demeurent incertaines. L'augmentation de la température des eaux de surface entraînera également un changement dans la répartition des espèces de poissons dans les parcs de la région des Grands Lacs. On s'attend à ce que les espèces situées à l'extrémité nord de leur aire, comme les centrarchidés (achigan à petite bouche et crapet) et les percichthyidés (bar blanc et baret) se propagent davantage. Le doré et la perchaude pourraient se replier dans les régions aux eaux plus froides. Dans le parc national de la Mauricie, l'omble chevalier, qui se trouve à l'extrémité sud de son aire, sera probablement particulièrement vulnérable au réchauffement des eaux. On a également prévu la disparition généralisée des salmonidés lotiques dans le parc.

Les cinq parcs nationaux de l'Ontario, parce qu'ils sont situés près de plans d'eau ou sur des îles, souffriront moins de la plus grande fréquence et l'intensité accrue des incendies de forêt dans une grande partie du nord et de l'est de l'Ontario (l'indice forêt-météo devrait augmenter entre 1,5 et 2 fois dans des conditions de redoublement du CO_2 – Thompson *et al.*, 1998). On prévoit néanmoins que les incendies de forêt saisonniers deviendront plus graves dans quatre des cinq parcs nationaux de cette province. L'accroissement de cette perturbation (particulièrement en conjonction avec les accroissements prévus au chapitre des perturbations dues aux maladies et aux insectes) aura un effet à la baisse sur la répartition des classes d'âge des peuplements forestiers. Un tel changement nuirait aux espèces animales des peuplements forestiers mûrs (comme l'orignal et le pékan), tout en accroissant les habitats pour l'ours, le castor, le cerf (le cas échéant) ainsi que pour d'autres espèces qui profitent des habitats d'espèces pionnières en augmentation à cause du nombre accru d'incendies de forêt. Cela revêt une importance particulière dans le cas du parc national Pukaskwa en raison du programme de protection du caribou des bois qui y est appliqué.

La combinaison d'un climat plus chaud et d'un accroissement des perturbations aurait pour effet de rendre les systèmes naturels plus vulnérables à la propagation des espèces envahissantes non indigènes. Déjà, la Pointe Pelée compte plus d'espèces exotiques que tout autre parc national au Canada (247 espèces végétales et animales) et verra tout probablement l'introduction de nouvelles espèces terrestres caroliniennes à mesure qu'elles progresseront vers le nord. Soixante-dix espèces végétales du parc national de la

Mauricie sont considérées comme étant rares ou dignes d'un intérêt spécial; l'impact du changement climatique sur l'aire de distribution de ces plantes constituera une préoccupation particulière en regard des efforts de conservation déployés dans le parc.

Parcs des Prairies

Les parcs nationaux des Prairies, exception faite de ceux de la région de l'Arctique, devraient connaître les plus grandes augmentations de température dans des conditions de redoublement du CO_2. Les accroissements de température entraîneront une augmentation des taux d'évaporation, une diminution des niveaux d'humidité du sol et un nombre accru de sécheresses. Les répercussions des changements prévus dans les précipitations (augmentation des écoulements printaniers en raison de précipitations accrues pendant l'hiver et débits inférieurs pendant l'été) sur les conditions hydrologiques saisonnières sont également importantes pour les Prairies. À cause de la baisse des précipitations prévue, le débit de base pendant l'été pourrait diminuer dans les cours d'eau de plusieurs parcs des Prairies, et certains cours d'eau permanents pourraient devenir intermittents dans des conditions de redoublement du CO_2. On s'attend également à une hausse de la température de l'eau dans les cours d'eau et les rivières, ce qui se traduira par une moins grande quantité d'oxygène dans les systèmes aquatiques. Shuter *et al.* (1998) ont constaté que l'augmentation de la température et la baisse des niveaux de l'eau pourraient donner lieu à la migration de nombreuses espèces de poissons vers le nord, à raison d'à peu près 150 km pour chaque augmentation de 1 °C de la température moyenne.

Les changements de nature hydrologique se répercuteront également sur les terres humides et sur la sauvagine. Les espèces de cette catégorie qui se reproduisent dans de nombreux parcs des Prairies sont fortement influencées par la température en mai et par les précipitations au printemps. Des changements à ces deux variables provoqueront une modification dans les patrons de reproduction et dans la composition des espèces de la région. Le parc national Prince Albert abrite la deuxième plus grande aire de reproduction du pélican au Canada. Cette colonie, située sur l'île Heron dans le lac Lavalée, est la seule colonie de nidification du pélican d'Amérique entièrement protégée au Canada. Une baisse du niveau de l'eau dans ce lac pourrait avoir pour effet d'exposer les sites de nidification aux prédateurs. Le delta des rivières de la Paix et Athabasca, l'un des plus grands deltas continentaux au monde et une zone humide d'importance mondiale, se trouve également dans le parc national Wood Buffalo. La dynamique des terres humides aura une importance prépondérante pour la protection de la seule aire de reproduction connue de la grue blanche.

Plusieurs parcs de la région des Prairies sont situés sur des écotones marquant la transition entre la prairie et la forêt et entre la forêt et la toundra, et l'ampleur du changement climatique prévu dans cette région porte à croire que ces parcs seront probablement plus susceptibles de connaître des modifications écologiques que ceux de la plupart des autres régions. Selon une analyse de l'étude du changement climatique et du type de formation

des forêts effectuée par Lenihan et Neilson (1995), tous les parcs nationaux de la région des Prairies subiraient une transformation vers un autre type de forêt. Les forêts boréales de la région des Prairies subiraient des répercussions négatives, l'avancée pouvant atteindre de 100 à 700 km vers le nord (peut-être même jusqu'à l'extérieur du parc national Prince Albert). Les essences boréales finiraient par être remplacées par des essences méridionales tolérantes à la chaleur et par des prairies, supportant mieux les températures élevées et la sécheresse. Le parc national Wood Buffalo se trouve dans une zone de transition entre les biomes de la forêt boréale et de la taïga. Le type et le rythme de la pédogenèse pourraient entraver la migration des forêts boréales vers le nord au fur et à mesure du changement des conditions climatiques (la pédogenèse ne se ferait pas aussi rapidement que le changement climatique prévu dans la région).

Les conditions de sécheresse étant accentuées, les incendies de forêt deviendraient plus fréquents et plus intenses dans le nord de la région. Selon les scénarios de redoublement du CO_2, l'indice forêt-météo (IFM) augmentera de 1,0 fois dans la région du parc national Elk Island, de 1,5 à 2 fois dans la région du parc national du Mont-Riding, et de plus de 2,4 fois dans la plupart des régions du parc national Wood Buffalo (Thompson *et al.*, 1998). Les perturbations attribuables aux incendies modifieront à la baisse les distributions des classes d'âge des forêts, ce qui se répercutera sur les espèces qui utilisent les peuplements forestiers mûrs. Un accroissement des perturbations attribuables aux incendies contribuerait à une plus grande fragmentation de l'habitat forestier et accélérerait l'expansion de la prairie dans les parcs de la région des Prairies.

Les modifications du biome et la perte de forêts anciennes diminueront les chances de survie de nombreuses espèces sauvages qui dépendent de la forêt boréale et donneront lieu à un changement graduel au profit des espèces adaptées aux prairies et aux écosystèmes forestiers tempérés. Les espèces animales des les prairies, comme le cerf, le bison, la sturnelle de l'Ouest et le blaireau, auraient plus de chances de s'adapter aux nouvelles conditions. Les ours pourraient également en tirer profit puisqu'ils prospèrent dans les paysages forestiers variés résultant des incendies de forêt. Si la forêt de conifères, habitat préféré du caribou des forêts dans le parc national Prince Albert, recule au-delà des limites du parc, cette espèce pourrait disparaître. Le parc national des Prairies abrite plusieurs espèces rares ou menacées dont la chevêche des terriers et l'une des dernières colonies de chiens de prairie au Canada. Même si ces espèces pouvaient profiter de l'extension des prairies dans d'autres aires protégées, il faudra poursuivre les recherches pour déterminer les répercussions du changement climatique sur ces populations (dans un scénario, Rizzo et Wiken, le modèle de 1992 prévoit l'apparition d'un désert semi-aride dans cette région).

Parcs de la Cordillère occidentale

Même s'ils ne connaissent pas l'ampleur des variations latitudinales dans les espèces prévisibles dans certaines autres régions, les parcs de la région de la Cordillère seront les

plus susceptibles de présenter des modifications dans l'altitude. À lui seul, le parc national Banff compte quarante et une espèces végétales dont l'aire de distribution entière se trouve à l'intérieur des limites du parc et qui seront par conséquent particulièrement sensibles au changement climatique. Les changements prévus dans la température et les précipitations conduiront à l'élargissement des zones subalpine et montagnarde. Les écosystèmes subalpin et montagnard s'agrandiront, leurs limites s'élevant davantage en altitude, progression favorisée par le plus grand nombre d'avalanches dégageant des passages le long des pentes alpines. On prévoit qu'une augmentation de la température annuelle moyenne de 3 °C seulement permettrait à l'écotone alpin-subalpin de s'élever de 500 à 600 mètres. Il en résulterait une diminution de la superficie de l'écosystème alpin ainsi que la disparition de certaines espèces alpines incapables de s'adapter. Ces changements entraîneront probablement une perte nette au niveau de la biodiversité dans les parcs nationaux de la Cordillère occidentale à mesure que certaines espèces végétales poussant à haute altitude disparaîtront du sommet des montagnes. On suppose que les effets de l'enrichissement en CO_2 sont plus importants pour les végétaux poussant en haute altitude et qu'ils pourraient, de ce fait, avoir un plus grand impact sur les écosystèmes montagnards. On n'a encore qu'une compréhension limitée de ce phénomène et des interactions avec les autres répercussions du changement climatique. Seul l'écosystème du Douglas taxifolié / pin ponderosa / chiendent commun des Rocheuses canadiennes, dans la région de Dry Gulch-Stoddart Creek du parc national Kootenay, profiterait d'une augmentation des températures en été et de conditions estivales plus sèches.

Selon tous les scénarios des MCG, les températures hivernales moyennes demeureraient en deçà du point de congélation. Ainsi, des précipitations plus importantes en hiver entraîneront probablement une augmentation de la neige accumulée dans tous les parcs de la Cordillère occidentale, ce qui aurait des répercussions à plusieurs égards sur les parcs. Les déplacements des animaux y seraient plus difficiles en raison de la plus grande quantité de neige. Les vallées, à la couverture neigeuse mince, servent d'aires d'hivernage aux troupeaux d'ongulés. Si cette couverture s'épaississait, ces troupeaux pourraient migrer plus avant dans la vallée à la recherche de nourriture pendant l'hiver. Dans certains parcs, la nécessité, pour certains grands mammifères, de se déplacer vers des aires moins élevées pour échapper à un couvert nival épais se répercute sur la mortalité animale. Par exemple, la route transcanadienne et la voie ferrée du Canadien Pacifique traversent le parc national Banff; ce couloir de circulation joue un rôle déterminant du point de vue de la mortalité des espèces sauvages. Bien que l'on ait érigé des clôtures en bordure de la route et que des passages (supérieurs et inférieurs) aient été ajoutés, la voie ferrée demeure source de préoccupations.

On s'attend aussi à des avalanches plus fréquentes et plus importantes. En raison de la hausse prévue des températures hivernales, le manteau neigeux pourrait comporter des couches instables susceptibles de provoquer un plus grand nombre d'avalanches pendant l'hiver. Ces dernières créeraient des alpages plus longs et plus larges dans les forêts

subalpines et déverseraient plus de débris dans les cours d'eau. Les alpages ainsi créés viendraient s'ajouter aux habitats existants pour certaines espèces sauvages comme la marmotte des Rocheuses. Toutefois, une augmentation du nombre d'avalanches constitue un risque pour les humains, tant dans l'arrière-pays que dans les régions développées et le long des couloirs de circulation. Par conséquent, les coûts liés aux situations d'urgence pourraient augmenter.

Des températures plus clémentes au printemps et à l'automne auront pour effet d'allonger la saison de la fonte des glaciers d'au moins un mois dans la partie sud des Rocheuses. Les glaciers de faible élévation, comme le Peyto dans le parc national Banff, devraient connaître un retrait rapide par suite d'un réchauffement du climat. Les glaciers de moins de 100 m pourraient complètement disparaître au cours des 20 prochaines années (Brugman *et al.*, 1997). Les glaciers dont la zone d'accumulation est plus élevée, comme le champ de glace Columbia dans le parc national Jasper, seront moins touchés et pourraient même s'avancer lentement à cause de l'augmentation prévue dans les chutes de neige.

Une modification des conditions hydrologiques attribuable à la fonte des glaciers et une crue printanière modifiée (en juin plutôt qu'en mai) se répercuterait sur l'environnement des cours d'eau et sur les activités de loisirs. Une accélération du retrait glaciaire aurait pour effet d'augmenter l'écoulement en été jusqu'à ce que les glaciers aient nettement diminué. Blais *et al.* (1998) ont observé des concentrations élevées de composés organochlorés dans la glace et la neige des glaciers dans les chaînes de montagnes de l'Ouest canadien (les concentrations étaient de 10 à 100 fois plus élevées entre 770 et 3 100 m d'altitude). Ces polluants amenés par transport à grande distance se sont accumulés au fil des décennies. Une fonte rapide des glaces pourrait entraîner la libération de quantités suffisantes de ces polluants pour que l'on puisse craindre pour l'état des écosystèmes aquatiques en aval. En principe, les lacs alpins, ayant une basse température et de courtes saisons de croissance, sont oligotrophes (Achuff et Pengelly, 1986). Une température moyenne plus élevée entraînerait une légère augmentation de celle des lacs. Toutefois, il est peu probable que ces plans d'eau, alimentés par les glaciers, se réchauffent suffisamment pour que les patrons de croissance des espèces aquatiques soient modifiés. Des températures plus élevées tout au long de l'année devraient allonger la saison inter-glacielle dans les lacs alpins, subalpins et montagnards. La région des terres humides des lacs Vermillion du parc national Banff est très vulnérable aux changements du niveau d'eau et pourrait donc souffrir d'une modification des conditions hydrologiques saisonnières.

On prévoit que les incendies de forêt, les poussées de maladie et les infestations par les insectes deviendront plus nombreux dans les parcs de la Cordillère occidentale. Les conséquences écologiques de ces perturbations forestières accrues dans cette région à la topographie complexe de la région demeurent pour la plupart inconnues.

Parcs du Pacifique

On prévoit que les parcs nationaux de la région du Pacifique, tout comme ceux de la région de l'Atlantique, connaîtront des changements climatiques, moins marqués toutefois qu'à l'intérieur du continent. Contrairement à ce qu'on prévoit sur la Côte Atlantique, le relèvement isostatique sur la côte du Pacifique compensera dans une certaine mesure l'élévation du niveau de la mer. Le littoral des parcs nationaux de la région du Pacifique est peu vulnérable au changement physique résultant d'une élévation du niveau de la mer (Shaw *et al.*, 1998a). L'effet combiné d'une légère élévation du niveau de la mer et d'une intensification des tempêtes pourrait néanmoins modifier le niveau et le degré de salinité de l'eau souterraine ainsi que l'équilibre entre les habitats estuariens d'eau douce et d'eau salée dans certaines régions côtières. Il pourrait en découler des répercussions pour les oiseaux de mer, les crustacés et coquillages et d'autres espèces des estuaires.

L'augmentation prévue de 3,5 °C de la température à la surface de la mer dans le nord-est du Pacifique au cours des 50 prochaines années pourrait être le changement qui aura le plus de répercussions sur les écosystèmes marins, côtiers et fluviaux des parcs nationaux de cette région (affaiblissent la remontée de nutriants, fraye, migrations et introduction d'espèces du sud). Une augmentation de la température de la mer devrait se traduire par une plus grande fréquence et à une plus large distribution des proliférations planctoniques. Des eaux plus chaudes seraient favorables à l'augmentation des populations d'espèces du sud comme le maquereau et le germon, prédateurs et grands concurrents du saumon. On se sait pas avec certitude de quelle manière les peuplements d'algues brunes réagiront aux changements de température; toutefois, ils pourront probablement s'adapter lentement à l'élévation du niveau de la mer.

Les habitats des parcs du Pacifique, tout comme ceux des parcs de la Cordillère occidentale, subiront des modifications dans l'altitude des habitats. Les écorégions de la toundra alpine et de l'épinette des montagnes, bien qu'on ne les retrouve que sur les hauteurs des chaînons Reine-Charlotte, sur la bordure nord de la réserve de parc national Gwaii Haanas, pourraient être gravement touchées par les changements de température et de précipitations prévus. L'écorégion de l'épinette des montagnes est susceptible de changer d'altitude, par suite d'une modification du seuil d'enneigement et de la saison de croissance à la limite supérieure de la zone, et l'épinette serait peu à peu remplacée par la pruche occidentale à la limite inférieure. La toundra alpine est particulièrement menacée par les conditions favorisant l'empiètement des espèces de la zone de l'épinette des montagnes. Selon la superficie de l'habitat alpin restant, certaines espèces alpines pourraient disparaître du parc. Dans la réserve de parc national Kluane, il se pourrait que des espèces actuellement présentes plus au sud se propagent dans le parc à mesure que les conditions deviendront plus clémentes. Dans un environnement perturbé, les espèces envahissantes ayant des stratégies de colonisation agressives seraient favorisées. Il pourrait également survenir des changements dans les distributions selon l'altitude, les

espèces montagnardes, subalpines et alpines se déplaçant progressivement vers les hauteurs. Si la limite forestière avançait, il pourrait en résulter une réduction de l'habitat des espèces subalpines, puis la disparition de certaines espèces. Dans la réserve de parc national Pacific Rim, la forêt d'épinettes de Sitka pourrait progresser vers l'intérieur des terres étant donné que cette communauté tolère mieux les conditions d'humidité moyenne. Des conditions plus sèches et des étés plus chauds pourraient favoriser la progression des communautés de Douglas taxifolié. Ces arbres ayant une durée de vie de plusieurs centaines d'années, les effets des changements d'espèces pourraient être visibles pendant des siècles.

L'augmentation attendue du ruissellement tout au long de l'année pourrait permettre la création de nouvelles aires d'alevinage et de nouveaux habitats d'hivernage dans les cours d'eau où ne se produisait pas auparavant la migration des saumons. Cela pourrait limiter dans une certaine mesure la progression d'espèces du sud. On ne connaît pas avec certitude l'impact qu'aurait sur la migration et la fraye du saumon l'avancement dans la région de la période de pointe des écoulements (en mai plutôt qu'un juin). Le saumon fait à ce point partie intégrante de la chaîne alimentaire terrestre pendant sa migration que d'autres espèces comme l'ours et le pygargue à tête blanche seraient affectées par une réduction de la population de saumons.

Contrairement aux glaciers de faible élévation du sud de la Colombie-Britannique, ceux de la réserve de parc national Kluane ont progressé. On prévoit que cette tendance se maintiendra malgré une augmentation de la température pendant toute l'année. On prévoit que les chutes de neige pendant l'hiver augmenteront et que les zones d'accumulation sont suffisamment élevées pour que les glaciers continuent à progresser. Dans le parc national Kluane, les niveaux plus élevés de précipitation et de fonte des glaciers devraient entraîner un relèvement des eaux dans plusieurs lacs importants. Il en résultera une diminution de l'île du lac Bates, lieu de nidification de sternes arctiques, de goélands cendrés et de goélands argentés. Le relèvement du niveau des eaux pourrait entraîner le déplacement de la population nicheuse de cygne trompette qui se trouve au confluent des ruisseaux Alder et Fraser.

Parcs de l'Arctique

Le changement climatique aura ses effets les plus marqués dans les parcs nationaux de l'Arctique. Étant donné que les conditions ambiantes (température, luminance, saison de croissance) sont presque à la limite des conditions de vie dans l'Arctique, les écosystèmes de cette région seront tout probablement les plus vulnérables.

L'ampleur de l'augmentation des températures saisonnières dans la région résulte en partie de la diminution de la capacité de réflexion en raison des plus courtes périodes de couverture nivale ou glacielle. Ces changements ont également des répercussions importantes sur l'environnement. Les augmentations de température prévues

entraîneraient une prolongation de la saison de croissance et permettraient une invasion par des espèces que l'on trouve habituellement plus au sud. Dans la zone bioclimatique herbacée du parc national Quttinirpaaq (auparavant la réserve de parc national de l'Île-d'Ellesmere) la végétation de la toundra pourrait devenir plus présente à mesure que la température de l'air, combinée à une plus grande humidité du sol et l'enfoncement de la couche active de pergélisol (la limite de la zone de pergélisol pouvant se déplacer jusqu'à 500 km vers le nord), fournirait des conditions plus favorables à la croissance. De plus, les espèces végétales de toundra pourraient être de plus en plus présentes sur les terres nues du parc national Aulavik. Plus au sud, on trouve dans le parc national Tukut Nogait des espèces végétales rares de Béringie qui seraient affectées par un climat plus chaud. On peut prévoir que l'aire de distribution des plantes qui poussent bien dans des conditions humides, comme les carex, les saules et les linaigrettes, s'étendrait. On pourrait assister à une invasion accrue par des espèces boréales du sud, et la végétation de toundra à croissance lente (lichens, plantes coussinets) pourrait être incapable de soutenir la concurrence et devoir se déplacer vers des aires plus élevées. On prévoit que la limite forestière s'avancera de 200 à 300 km vers le nord dans toute la région. Dans les parcs nationaux Ivvavik et Vuntut, qui constituent la zone de transition entre la toundra du bas Arctique et les régions boisées subarctiques, les zones boisées pourraient s'étendre. À la limite sud de cette région, les communautés végétales du parc national Nahanni changeront non seulement de latitude, mais aussi d'altitude. Les zones de basses terres et les zones montagnardes progresseront en altitude, entraînant la réduction des zones de toundra subalpine et alpine. On prévoit que les peuplements d'épinettes noires seront repoussés, en partie du moins, par les forêts mélangées, le sapin baumier, le pin blanc et l'épinette blanche, caractéristiques d'une province écoclimatique froide.

Ces changements dans la distribution et dans l'abondance de la végétation auront d'importantes répercussions sur les espèces sauvages des parcs. Le lemming est une espèce clé dans le parc national Aulavik parce que de nombreux oiseaux de proie et autres prédateurs en dépendent. Kerr et Packer (1998) prévoient que le réchauffement entraînera d'importantes réductions des aires de distribution du lemming, ce qui aura des conséquences considérables pour l'environnement arctique de ce parc. La population de bœufs musqués du parc national Tukut Nogait, qui vit à la bordure sud de son aire de distribution, est particulièrement menacée par les déplacements d'espèces végétales. Une croissance végétale plus riche pourrait donner une nourriture plus abondante en période estivale; toutefois, si les conditions hivernales se traduisaient par un manteau neigeux plus épais et par plus de couches de glace, les populations en souffriraient. De plus, le bœuf musqué pourrait complètement disparaître du parc si les espèces végétales de la taïga deviennent trop abondantes. Des changements dans les populations de caribou et de bœuf musqué entraîneront certainement des modifications dans les populations de prédateurs comme le grizzli, le carcajou et le loup. La population d'orignaux du parc national Vuntut pourrait tirer avantage du changement climatique si, par suite de l'invasion des espèces végétales de la taïga, les habitats d'hivernage, comme les aires d'arbustes à feuilles caduques, offrant un bon couvert et une nourriture abondante, se développent. Le grizzly

profiterait de la présence accrue des arbustes et de l'accroissement de la population d'orignaux tant que les grands arbres n'en viendraient pas à dominer l'habitat. Cette espèce d'ours en souffrirait toutefois si les voies de migration du caribou étaient modifiées dans un nouveau régime hydrologique et(ou) si les populations de ce cervidé devaient souffrir de changements dans ses zones de mise bas et d'hivernage. Dans le parc national Nahanni, le déplacement ascendant des peuplements forestiers pourrait faire diminuer la superficie d'habitat du grizzly et du mouflon de Dall; toutefois des avalanches en plus grand nombre pourraient produire davantage d'habitats de prairie subalpine. Les loups pourraient profiter d'un accroissement de l'habitat des populations d'espèces-proies comme le cerf de Virginie et le cerf-mulet.

Une réduction de la glace de mer aurait aussi des répercussions importantes pour plusieurs parcs de l'Arctique. Avec l'augmentation des températures automnales, hivernales et printanières, on prévoit que dans les mers arctiques les saisons d'eaux libres seront plus longues (jusqu'à 90 jours de plus dans la mer de Beaufort) et la couverture de glace sera moins épaisse. Cela aura des répercussions considérables sur les mammifères marins. Une diminution des glaces pourrait présenter des avantages pour certains mammifères (les baleines); toutefois, le réchauffement climatique aura des répercussions défavorables sur les espèces qui dépendent de la glace de mer et de la neige pour se mettre à l'abri et élever leur progéniture (comme l'ours polaire, le phoque annelé, le renard arctique et le lièvre arctique). Tout déplacement des populations d'espèces-proies touchera les grands prédateurs comme le loup arctique, l'ours polaire ainsi que les charognards comme le renard. Si des changements modifiaient l'ampleur et le type du manteau glaciel, les ours polaires auraient moins accès à leurs proies et devraient se déplacer vers le nord ou demeurer plus longtemps sur le continent; ils auraient plus de difficulté à se nourrir et leur taux de reproduction chuterait. Étant donné que la population d'ours polaires dans le parc national Wapusk se trouve déjà près de la limite sud de son aire de distribution, on prévoit que cette population disparaîtra complètement du parc. Une diminution de la formation de la glace de mer pourrait limiter les migrations entre les îles et les échanges génétiques entre les troupeaux de caribous des îles de l'Arctique, ce qui entraînerait inévitablement un appauvrissement du stock génétique du caribou de Peary de l'île Banks.

Une couche de neige plus épaisse, avec ou sans couches de glace à l'intérieur, forcerait les caribous et les bœufs musqués à dépenser plus d'énergie pour se nourrir. Cela pourrait avoir pour résultat net une moins bonne alimentation et une baisse du taux de reproduction. De plus, le caribou est sensible aux insectes qui, dans des conditions plus chaudes, seraient présents en plus grand nombre pendant une plus longue période. Russel (1993) a prévu que les agressions conjuguées dans le parc national Quttinirpaaq entraîneront une chute allant de 40 % à une infécondité complète dans le pire des cas. Les changements survenant dans les populations fauniques et les itinéraires migratoires influeront beaucoup sur les cultures traditionnelles de l'Arctique du Canada.

L'élévation du niveau de la mer aura des répercussions variées dans les parcs de la région de l'Arctique. Le relèvement isostatique dans la région du parc national Quttinirpaaq compensera en grande partie l'élévation prévue du niveau de la mer tandis que l'affaissement des sols dans les parcs nationaux Auyuittuq et Ivvavik viendra ajouter à cette élévation (celle-ci atteignant entre 0,5 et 1 m au cours des cent prochaines années). La ligne de côte du parc national Ivvavik a été classée de modérément à hautement vulnérable aux répercussions physiques de l'élévation du niveau de la mer (Shaw *et al.*, 1998a). Une grande part de la population canadienne d'oies des neiges et de canards de mer qui utilisent les zones côtières comme point d'escale devront d'adopter d'autres aires si le changement climatique entraîne une réduction des habitats côtiers et(ou) une plus grande érosion des rivages. La ligne de côte du parc national Aulavik a été classée comme modérément vulnérable, les endroits les plus sensibles étant les plages situées devant des falaises de sédiments non consolidés, les deltas et les estuaires. Les rivages rocheux des parc nationaux Quttinirpaaq et Auyuittuq sont peu vulnérables.

Au cours de la dernière période glaciaire, le parc national Vuntut est demeuré en majeure partie à l'abri de la glaciation. Cela en fait une zone d'une « valeur unique pour la recherche paléoécologique » (Parcs Canada, 1995). Malheureusement, les restes préhistoriques fossilisés pourraient souffrir de changements dans les conditions hydrologiques et la végétation. Si les tourbières disparaissent, les restes fossilisés seront exposés aux agents oxydants et se décomposeront. De plus, une plus forte érosion des rives de la rivière Old Crow pourrait mener à l'élimination de nombreux sites d'intérêt archéologique dont font état les inventaires du parc.

Conclusions

Le changement climatique, qui sera un élément prédominant de la protection écologique au cours du XXI^{e} siècle, lance à Parcs Canada un défi sans précédent. Le changement climatique représente à la fois une menace et des possibilités pour diverses espèces et diverses collectivités écologiques du système national des parcs. L'importance relative du changement climatique pour les zones protégées de chaque région du Canada et, qui plus est, des parcs individuels différera donc. Les espèces individuelles répondant au changement climatique, les collectivités écologiques actuelles commenceront à se dissoudre et à se reconstituer en nouveaux ensembles. La biogéographie dynamique occasionnée par le changement du climat du globe modifiera bel et bien les «règles» de la conservation écologique. En conséquence, il convient d'analyser et de débattre en profondeur le rôle stratégique de Parcs Canada dans une ère de changement climatique.

Bien que cet aspect ne soit pas le premier objectif de la présente étude, il est clair que le changement climatique modifiera les possibilités récréatives et les régimes de visite dans les parcs nationaux. Le réseau des parcs nationaux du Canada représente une ressource touristique de premier plan. Les sommes dépensées par les touristes qui visitent les parcs nationaux (environ 1,2 milliard de dollars en 1994-1995 - Parcs Canada, 1998a) ont une grande importance pour l'économie de nombreuses communautés. On ne sait pas dans quelle mesure une modification du paysage naturel, de la faune, des aspects culturels ou

des possibilités récréatives dans les parcs nationaux pourraient rendre les parcs moins attrayants aux yeux des visiteurs.

Les nombreuses lacunes soulignées dans la présente analyse au chapitre de nos connaissances font ressortir la nécessité de mettre sur pied un programme de recherche dans le but d'examiner les répercussions du changement climatique sur l'environnement et sur le tourisme dans les parcs nationaux. Voici quelques-unes des pistes de recherche initiales :

- Une réévaluation complète du plan du réseau des parcs nationaux du Canada dans le contexte du changement climatique.
- Une évaluation plus détaillée des répercussions au niveau de chaque parc, examinant de manière explicite les répercussions du changement climatique pour les objectifs de gestion de chaque parc ainsi que « l'état souhaité ». Les évaluations des plans de gestion des parcs pourraient comprendre les éléments suivants : l'identification des sites historiques et archéologiques à risque face aux répercussions du changement climatique, l'analyse de la vulnérabilité au changement climatique des espèces canadiennes en péril, un examen de la manière dont le changement climatique pourrait favoriser l'envahissement des habitats des parcs par de nouvelles espèces et de la manière dont les pratiques actuelles de gestion pourraient influencer les trajectoires évolutives;
- Une analyse des répercussions du changement climatique pour le tourisme dans les parcs au Canada, y compris de la manière dont le changement climatique modifierait les conditions et l'expérience de diverses activités de loisirs (durée de la saison, accès et sécurité, infrastructure), la compatibilité des changements de nature récréative avec les objectifs des parcs, les répercussions économiques de la modification des régimes d'activité touristique pour Parcs Canada et les communautés environnantes.

Parcs Canada devrait également faire figure de chef de file en créant une table ronde nationale (ou bi-nationale) sur le changement climatique (réunissant des représentants des organismes des aires protégées, du milieu scientifique et d'autres groupes d'intervenants) sur les aires protégées et le changement climatique. Ce groupe de travail cernerait les besoins clés en matière de recherche et examinerait la gamme des voies d'adaptation (gestion des incendies et des invasions, choix des parcs et critères de conception) ainsi que les options d'atténuation des gaz à effet de serre (nouvelles normes d'efficacité des parcs automobiles, projets pilotes sur des technologies d'énergies renouvelables, et séquestration du carbone par la gestion et la restauration des paysages).

Le changement climatique peut en principe saper des décennies d'efforts de conservation notables au Canada et expose à une menace ce patrimoine intergénérationnel. Nous espérons que la présente évaluation informera les lecteurs du défi que pose le changement climatique pour la protection de l'environnement, qu'elle renforcera l'intégration du changement climatique à la planification stratégique et à la formulation des politiques de Parcs Canada et qu'elle inspirera une vision plus large du rôle des aires protégées à une époque de changement climatique d'origine anthropique.

1.0 Introduction

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Naturally occurring concentrations of certain radiatively active gases in Earth's atmosphere (water vapour, carbon-dioxide, methane, nitrous oxide) trap long wave energy radiated from the planet's surface and atmosphere, and warm the global mean near-surface temperature 33°C. Life as it is currently known would not be possible without the warming influence of this natural 'greenhouse effect.'

The theory that industrial emissions would alter the atmospheric concentration of greenhouse gases (GHG) and influence the global climate system was first formulated by the Swedish chemist Svante Arrhenius over 100 years ago. Contrary to Arrhenius' (1896) conclusion that the world's coal and other fossil fuel resources would be exhausted before there would be an appreciable human influence on global climate, the Inter-governmental Panel on Climate Change (IPCC, 1995a) has declared, 'the balance of scientific evidence indicates a discernible human influence on global climate.' While the magnitude and timing of global climate change remain uncertain, it would seem humanity has unwittingly set in motion a global climatic experiment.

Analyses of atmospheric gases obtained from glacial ice cores have indicated that in 1990, concentrations of carbon-dioxide (CO_2) and methane have increased 30% and 145% respectively, over pre-industrial levels. At 358 parts per million (ppm) in 1994, global atmospheric CO_2 levels were higher than at any time in the past 220,000 years. According to the Intergovernmental Panel on Climate Change (IPCC, 1995b) 'best estimate' global emission scenario (IS92a), atmospheric levels of CO_2 could climb to over 730 ppm by 2100 (Office of Science and Technology Policy, 1997). Even if the greenhouse gas emission reduction commitments contained in the Kyoto Protocol were fully realized, the resulting reductions would only delay the IS92a concentrations by a decade (Canadian Climate Program Board, 1998). Considering the tremendous social, economic and political difficulties of achieving the greater than 50% GHG emission reduction required to stabilize atmospheric levels of GHG at currently elevated levels (IPCC, 1994) and the inertia within the global climate system, some degree of human-induced climate change will be realized in the twenty-first century.

Assessing how the global climate system may respond to human amplified greenhouse gas levels is an incredibly complex undertaking. The IPCC second assessment (1995a)[2] represented the combined work of more than 2000 of the world's leading climate scientists, and projected a global mean, near-surface temperature increase of between 1.5 and 4.5°C by 2100 (with a 'best estimate' of 2.5°C). To put this magnitude of climate change in context, global average temperatures increased between 4 and 7°C over the 5000 years of the last deglaciation.

Acknowledging some regional exceptions, climatic change is generally expected to be more pronounced at higher latitudes. Using the results of the Canadian Centre for Climate Modelling and Analysis (CCCma) second generation General Circulation Model (GCM), temperature change in the continental areas of Canada would be double the global average at 50°N and amplified by a factor of 3.5 at 80°N (Etkin *et al.*, 1998). Climate change of this magnitude would have important consequences for the Canadian economy and its ecosystems.

The Canada Country Study (Environment Canada, 1998) provided an initial assessment of the many challenges and opportunities climate change will pose for the nation's regions and major economic sectors. Despite the large volume of research represented in this national assessment, much remains to be done to address the gaps in our knowledge regarding the impacts of climate change and pausible adaptation responses.

One area that has received comparatively less research attention by the climate change impact assessment community, is 'natural' and semi-managed ecosystems. Despite their important role in ecological conservation, relatively little has been done to assess the implications of climate change for Canada's national parks or other protected areas. Publications by Parks Canada staff (Rowe, 1989; Lopoukhine, 1990 and 1991) identified the importance of climate change as a potential ecological stressor and outlined some of the broad issues related to climate change and the national park system. A decade later, little has been done to address the knowledge gaps they identify. A small number of studies have been undertaken in individual national parks (Vetsch, 1986; Staple, 1994; Gomer, 1999; Hui, 2000), but no systematic regional or national assessment has yet been completed. Staple (1994) indicated that the lack of a Parks Canada policy on climate change might, in part, explain the limited discussion and research to date.

In the 1997 *The State of the National Parks* report (Parks Canada, 1998a), climate change was already identified as a stressor causing significant ecological impacts in seven parks (Fundy, Grasslands, Gwaii Haanas, La Mauricie, Mingan Archipelego, Pacific Rim, and St. Lawrence Islands National Parks). Paleoecological evidence and ecological modelling analyses of the impacts of projected climate change on Canadian ecosystems, suggest the salience of climate change will increase markedly for Parks Canada in future decades.

Terrestrial ecosystems are greatly determined by climate, particularly temperature and precipitation (Holdridge, 1947; Woodward, 1987). As climatic zones change, so too will the composition and spatial extent of ecosystems. Paleoecology offers insight into the kinds of ecosystem change that could be expected under projected climate change. Paleoecological research of the last deglaciation of North America has shown that once significant ecosystems (e.g., spruce parkland) were markedly diminished as climate conditions changed (Webb, 1992). Ritchie (1987) discovered North American tree communities that existed 9000 to 3000 years ago with no modern analogues.

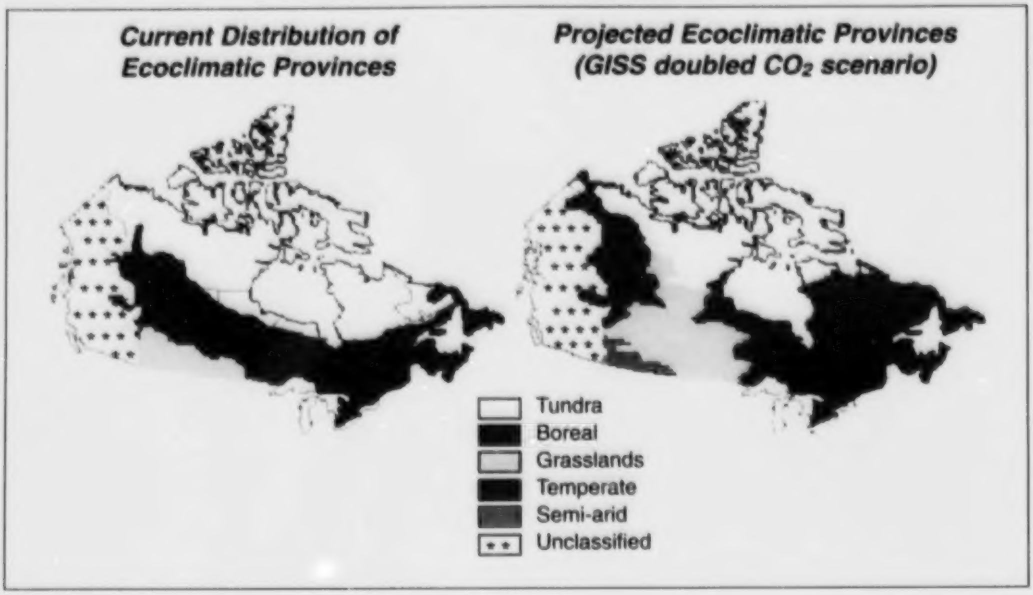
Species respond to climate change individually (Graham, 1988; Delcourt and Delcourt, 1991) and it is unrealistic to expect that current ecological communities will simply march northward' in unison. Instead, current ecological communities should be thought of as temporary associations that will disassemble as a result of different migration rates and adaptive tolerances, and 're-sort' into new ecological assemblages (Peters, 1990; Walker and Steffen, 1997). Although dramatic perturbations are possible in the short-term (Pearman, 1988), paleoecological evidence suggests the process of ecological sorting and eventual stabilization into communities adapted to the new climate regime will take place over centuries (Ritchie, 1987; MacDonald *et al.*, 1993).

As the projected magnitude of human-induced climate change is similar to the transition from the last glacial to interglacial period, the implications for ecosystem change are considerable. That this magnitude of climatic change is projected take place over a single century is more alarming still. The rate of human-induced climate change is likely to be the most disruptive threat to ecosystems, as it may out pace the physiological ability of some species to adapt or migrate to areas with tolerable climate limits (Anderson *et al.*, 1998). Most biologists agree that the rate of climate change projected for the next 100 years would be too great for evolutionary process, such as natural selection (Root and Schneider, 1993). Similarly, paleoclimatic research suggests few forest species would be able to disperse quickly enough in response to projected climate change (Martin and Haslett, 1995). Furthermore, human dominated landscapes (i.e., agriculture and urban areas) fragment the natural environment, compounding migration challenges. In short, the range of significant ecological stressors outlined in the 1997 State of the National Parks report (Parks Canada, 1998a) have diminished the inherant capacity of ecosystems to adapt to climate change.

The results of two studies examining how projected climate change may alter the location of terrestrial ecosystems indicate the magnitude of ecosystem change possible in Canada's national parks. Using nine climate parameters, Rizzo and Wiken (1992) modelled the spatial shifts in ecoclimatic provinces (broad landscapes with fundamentally similar ecological responses to climate) in Canada. Their model predicted large spatial shifts (Figure 1), with cool temperate forests expanding over much of eastern Canada south of James Bay, a 500km northward shift of the remaining boreal forest and emergence of semi-desert zone in southern Saskatchewan and Alberta. Applying the results of this study to Canada's national parks, only 7 of the 28 national parks in the study remained in the same ecoclimatic province under doubled-CO_2 conditions. The study did not attempt to examine how the composition of ecological communities would evolve.

A more recent study of the impacts of two climate change scenarios on forest vegetation formations in Canada (Lenihan and Neilson, 1995) revealed a similar magnitude of change in the national parks system. Interpreting the results of this study indicated only 10 of the 38 national parks would be classified in the same forest vegetation formation under the GISS scenario and even fewer (8) under the GFDL scenario.

Figure 1 - Projected Shifts in Canada's Ecoclimatic Provinces



Adapted from Rizzo and Wiken, 1992

Due to the number of other important influencing factors (soil conditions, availability of water, and species migration rates), these initial projections of ecological restructuring are unlikely to reflect the eventual composition and distribution of ecoclimatic provinces or forest vegetation formations 100 years from now. Nonetheless, the dynamic biogeography implied by these studies is illustrative of the magnitude of ecological change that Canada's protected areas may undergo.

Solomon (1994:1) noted, "In contrast to the emerging picture of a (potentially) rapidly changing world, most parks are designed and maintained on the assumption of environmental stability, and many have been established to preserve specific biotic communities in perpetuity." Any conservation strategy based on a system of isolated protected areas ('conservation islands') becomes tenuous if these areas become uninhabitable to the species and ecosystems they were designated to protect. In short, the spatial displacement of ecosystems into and out of the stationary boundaries of Canada's system of national parks will pose an unparalleled challenge to Parks Canada's mandate of maintaining ecological integrity in a representative sample of the nation's ecosystems. If Canada's system of national parks continues to be managed without contingencies for climatic change, the intergenerational conservation legacy of the parks system is likely to be diminished substantially.

This report is intended to provide a summary of the sensitivity of park ecosystems and visitor activities to projected climate change and consider the implications for the continued delivery of park mandates in an era of global climate change. The specific objectives of the study were:

1. To assemble climate change scenario data from selected General Circulation Models for each of Canada's national parks[3];
2. To complete an initial assessment of how projected climate changes are expected to impact abiotic features, individual species, ecosystems, and visitor activities in each national park, and;
3. To identify critical gaps in our understanding of climate change impacts on the national park system.

We stress that this analysis was, out of necessity, designed as a scoping exercise. Research on climate change and Canada's protected areas is currently limited and the extensive body of literature that indirectly pertains to climate change and the national parks remains disjointed. Time and budgetary constraints limited the level of research that could be undertaken. Discussion has focused on the potentially significant impacts and issues of concern for ecosystem managers and policy makers, as determined from the current scientific understanding of climate change implications for biodiversity, ecosystem structure and functional dynamics, and tourism related activities. Although some national parks appear to be more vulnerable to projected climate change, equal space was allocated to the overview of impacts in each park.

The report structure is as follows. Section two provides an overview of the methods used to construct the climate change scenarios and a summary of how the climate at each of Canada's national parks is projected to change over the next 100 years. A discussion of the potential impacts of climate change for each of the 38 national parks is contained in section three. Based on this analysis, management and policy implications, and future research needs are discussed in section four.

2.0 National Parks Climate Change Scenario Development

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For protected area managers to respond effectively to the challenges and opportunities posed by global climate change, understanding of current ecology-climate relationships and of the estimated range of projected climate change are required. This section provides climate change scenarios integral to future climate change impact assessment work and enables protected area managers to begin asking 'what if' questions related to climate change.

2.1 Climate Modelling

Climate change scenarios provide descriptions of plausible future climate conditions. Developing scenarios enables researchers to explore the sensitivity of a region to anticipated changes in climate. Climate change scenarios are most commonly constructed from the results of General Circulation Model experiments.

GCMs are three-dimensional mathematical models simulating the large-scale physical processes governing the global climate system (including the atmosphere, oceans, biosphere and cryosphere). These highly complex models represent the scientific community's most sophisticated understanding of the global climate system. GCMs incorporate over 200,000 equations to produce estimates of climate variables for a global network of grid cells. Using the most powerful supercomputers, a typical GCM experiment will still require computational time in excess of 1000 hours (Environment Canada, 1994).

Despite the complexity and growing sophistication of GCMs, climate scientists are careful to remind us that these models remain a coarse approximation of reality.[4] At the macro-scale, there are notable uncertainties regarding our understanding of atmosphere-ocean processes, the role of atmospheric aerosols, cloud physics, and various positive / negative feedbacks in the climate system (e.g., the release of methane from melting permafrost areas). The current generation of GCMs are incapable of incorporating micro-scale climatological influences. Because of limits in computational power, even GCMs with the highest horizontal resolution must greatly simplify subgrid features like mountain ranges and coastlines. Consequently, GCMs do not perform as well in coastal areas or areas of complex terrain and scientists have less confidence in GCM projections for variables where subgrid climate processes are important (e.g., precipitation).

The limited understanding of certain components of the global climate system has meant that climate modelling centres have modelled some processes differently. Even with standardized greenhouse gas emission and atmospheric aerosol scenarios, GCMs can generate different projections for global and regional climate change. There is no empirical basis to suggest which climate change scenario will best represent the future climate, under enhanced greenhouse conditions. Ultimately, this is an imponderable problem until experience validates one GCM over others. The results of more recent models are thought to be more reliable however, as they incorporate the most recent knowledge of the climate system.

Despite their limitations, GCMs represent the best tools available for examining how increased greenhouse gases will alter the global climate system. It is important to emphasize that scenarios derived from GCM experiments should not be regarded as definitive forecasts of future climate, but rather as internally consistent, physically plausible climate outcomes of a human-enhanced greenhouse effect. In order to adequately reflect the level of uncertainty associated with GCM outputs, a range of scenarios should be consulted in climate sensitivity research. The results of five climate change experiments performed at three modelling centres in Canada and the United States were reviewed in this project. Each model has been extensively validated and used in numerous climate impact assessments.

2.2 Scenario Development

Three criteria were used for selecting the most appropriate GCM scenarios for this project. There is commonly a lag between advances in the climate models and the work conducted by the climate impact assessment community. This time-lag was an important consideration for this exercise, as all of the impact assessment work reviewed as part of this scoping exercise was conducted with older GCM results (produced in the late 1980s or early 1990s). A large majority of published climate change impact studies relevant to Canada (e.g., see Table 1) have made use of the previous generation of GCM experiments from one or more of the following modelling centres: Environment Canada's - Canadian Centre for Climate Modelling and Analysis (CCCma), Princeton University's – Geophysical Fluid Dynamic Laboratory (GFDL) or NASA's – Goddard Institute for Space Studies (GISS). It was deemed important to include scenario data that would provide some measure of comparability and consistency with previous North American impact studies relevant to Canada's national parks.

The second criteria for GCM selection was to include scenario data from the most recent CCCma experiment with approximately doubled CO_2 levels (CGCM-I 2050) and the moderating effect of sulphate aerosols. The CCCma model is internationally recognized as one of the most advanced GCMs and the United States National Assessment of

Table 1
GCMs Used in a Sample of Impact Studies Relevant to Canada's National Parks

Impact Study	Sector / Study Focus	GCM Scenarios Utilized
Canada Country Study (1998)	Multi-sectoral	CCCma-II; GFDL; GISS; NCAR; UKMO
Clair *et al.* (1998)	Hydrology	CCCma-II
Kadonaga (1997)	Forests	CCCma-II and GISS
Lenihan and Neilson (1995)	Ecoregions	GISS; GFDL
Rizzo and Wiken (1992)	Ecoregions	GISS
Thompson *et al.* (1998)	Forests	CCCma-II

Climate Variability and Change has recommended the use of the new CCCma experiments above other currently available models. This data represents the state of the art in global climate change projections and will facilitate comparability with future impact assessments based on these scenarios.

The final criterion considered the longer-term prognosis for global CO_2 levels. To facilitate comparison of results, climate change impact studies have almost exclusively used scenarios based on the convention of doubled carbon-dioxide levels. Few studies have examined the implications of higher concentrations of CO_2, despite the IPCC (1994) assessment that the global social trajectory is toward an eventual quadrupling of CO_2 levels over pre-industrial levels.[5] Considering national parks are a heritage trust for future generations, it was thought incumbent to include a longer-term scenario based on the recent CCCma experiment with approximate tripled CO_2 levels (centred on the year 2090). Although this scenario far exceeds the planning frameworks of most organizations, it is nonetheless illustrative of the climatic conditions that some Canadians will experience within their lifetime.

The characteristics of each of the five scenarios reviewed for this project are summarized in Table 2. The atmospheric starting conditions (base year, CO_2 initialization level), length of experiment, and the number of years used to calculate the climate variables are described in the experiment conditions column. The reader is referred to the following papers for additional details about each of the GCMs: CCCma – GCM II (Boer *et al.*, 1992), GFDL-91 (Manabe *et al.*, 1991), GISS-95 (Russell *et al.*, 1995), CCCma – CGCM-I (Boer *et al.*, 1999). Data for each scenario were obtained directly from respective the modelling centre (either via web site or CD ROM).

An important difficulty associated with the applications of GCM outputs to regional climate impact assessments is the coarse spatial resolution of even the most advanced GCMs. GCMs produce estimates of climate variables for a network of grid cells that cover an area of tens of thousands of square-kilometres (160,000 in the case of the

Table 2 - Characteristics of GCMs Used to Construct National Park Scenarios

Modelling Centre	Model Type	Ocean Representation	Experiment Conditions
CCCma GCM-II	Equilibrium	Mixed Layer, Simplified 50m slab	1. Control Scenario: 20 year run initialized at 330 ppm CO_2 2. Forced Scenario: 20 year run after 'shocked' to new equilibrium of 660 ppm CO_2 3. Monthly means for control and forced scenarios calculated from 10 years of data (years 1 to 10 of each run)
GFDL	Transient	Full Three-Dimensional Circulating Ocean	1. Control Scenario: 100 year run initialized at 1958 CO_2 levels (315 ppm) 2. Forced Scenario: 100 year transient run with 1% compounded CO_2 increase per year 3. Monthly means for control and forced scenarios calculated from 20 years of data (years 60 to 80 of each run)
GISS	Transient	Full Three-Dimensional Circulating Ocean	1. Control Scenario: 74 year run initialized at 1958 CO_2 levels (315 ppm) 2. Forced Scenario: 74 year transient run with 1% compounded CO_2 increase per year 3. Seasonal means for control and forced scenarios calculated from 10 years of data (years 65 to 74 of each run)
CCCma CGCM-I *(Aerosol Run 1)*	Transient	Full Three-Dimensional Circulating Ocean	1. Forced Scenario: 201 year run, historic CO_2 levels from 1900 to 1989, 1% compounded CO_2 increase per year thereafter (to 2100), historic sulphate aerosol levels 1900 to 1989 2. Monthly means for control and forced scenarios calculated from user defined time-slices. For this project, 20 years of data were used for: ▪ 2050 scenario: years 2041 to 2060, approximate CO_2 doubling ▪ 2090 scenario: years 2081 to 2100, approximate CO_2 tripling

CCCma grid). Converting the output of GCMs to regional scenarios ('downscaling') is a process undergoing much discussion and refinement, and an adequate discussion is beyond the scope of this report.

A number of approaches to downscaling GCM scenarios for impact assessment research have been identified by Parry and Carter (1998). Two of the most common methods have been the 'nearest grid cell' approach (here termed the 'inclusive grid cell' approach), and applying objective interpolation techniques to grid cell data in order to add spatial detail. An important drawback of the first technique is that study areas in close proximity (with similar historic climates) can have quite different projected future climates because they

fall in different grid cells. The second technique overcomes this problem, but introduces a false sense of spatial precision.

Other more sophisticated techniques, including finer scale (~50km grid resolution) Regional Climate Model (RCM) output and establishing statistical relationships between large-scale (GCM grid cell) and small-scale (station observation) climate variables, are available. Both of these techniques are time-intensive and in the case of RCMs, rival GCMs in terms of expense and need for computing resources. The use of RCM output in impact assessments has been quite rare and as Hulme and Carter (1999) indicate, there remains a need to demonstrate the added value of such downscaling exercises for improving confidence in climate change descriptions. It should also be noted that at the time this report was prepared, doubled-CO_2 RCM results (based on CCCma-II boundary conditions) were only available for Western Canada (see Laprise *et al*, 1998).

The downscaling method used will depend on the both on the nature of the study and time and resource limitations. The method adopted for this project was the 'inclusive grid cell' approach. This method was the most suitable for the multiple (38), dispersed study areas of Canada's National Park system. The projected climate change values for each national park were derived from the GCM cell(s) in which each park was located (in whole or in part). Where a park was located within more than one grid cell, the values from each of the cells were averaged. Depending on the grid resolution of each GCM and the size of the park, this typically meant averaging the values of two to six GCM grid cells.

In order to determine the magnitude of projected climate change in the area of each national park, data from the control simulation and the forced experiment were obtained from the appropriate GCM grid cells.[6] Monthly data for temperature (mean) and precipitation (total mm) were obtained from the CCCma and GFDL models. Only seasonal data were available for the GISS model. The data for the CCCma and GFDL scenarios were subsequently converted to seasonal mean values (winter – December, January, February; spring – March, April, May; summer – June, July, August; fall – September, October, November). Projected change in temperature was determined by subtracting the results of the control simulation from the forced (enhanced CO_2) experiment. Precipitation change was calculated as a ratio of precipitation levels in the forced experiment versus the control simulation (i.e., forced experiment divided by the control simulation).

Carter *et al.* (1994) recommended the use of the World Meterological Organization most recent normal period of 1961 to 1990 to represent the climatological baseline. This period is assumed to be most representative of the climatic conditions ecosystems and human society are adapted to, however it is recognized this period of record may already reflect the influence of a human-enhanced greenhouse effect. Because station data reflect microclimate influences that GCM models do not, the historical baseline data for the 38 study areas in this investigation was derived from areal climate data contained in the Soil Landscapes of Canada Ecodistrict database (Agriculture and Agri-Food Canada, 1997).

This database contains monthly climate normals (1961-90) for each of the 1021 ecodistricts in Canada.[7] Baseline climate for each national park was derived from an area-weighted average of values from each ecodistrict represented within the park's boundaries.[8] The ecodistricts found within each national park and the derived temperature and precipitation normals are found in Appendices A and B. For comparative purposes, historic climate data from the monitoring station closest to the geocentroid of each national park (see Appendix C) have also been included in Appendix D.

Future research related to climate change and Canada's national parks will need to take advantage of refined GCMs and updated global GHG emission scenarios as they become available. For example, leading climate modelling centres are undertaking new experiments using the IPCC SRES emission scenarios developed as input into the IPCC Third Assessment Report.

2.3 Scenario Results

This section presents an overview of the most recent CCCma experiment results for winter and summer (Figures 2 to 9) temperature and precipitation change across Canada circa 2050 (~CO_2 doubling) and 2090 (~CO_2 tripling). A regional overview of the CCCma CGCM-I projections for the area of each national park is then presented in Table 3. Inter-model comparisons for the range of doubled-CO_2 scenarios are provided together with historic climate data for each national park in Appendices E and F.[9]

Projected Temperature Change in Canada:

Climate change is not expected to occur uniformly over the globe. Due to its northern latitude, regions of Canada are expected to warm considerably more than the global average. In the CCCma CGCM-I winter 2050 scenario (Figure 2), most of Canada is projected to warm between 4 and 6°C. The pattern of warming is noticeably stronger over the Hudson Bay region and areas of the far north (6 to 10°C), while relatively little warming (0 to 2°C) is expected for areas of Newfoundland, Labrador and Vancouver Island. The summer 2050 scenario (Figure 3) exhibited less warming, with 2 to 4°C warming anticipated for most of Canada. The few exceptions include 4 to 6°C warming in some areas of the Arctic region and 0 to 2°C (or even some cooling) for much of Atlantic Canada and southern British Columbia.

Figure 2 - CCCma CGCMI Temperature Scenario Over Canada (Winter 2050)

Figure 3 - CCCma CGCMI Temperature Scenario Over Canada (Summer 2050)

Figure 4 - CCCma CGCMI Temperature Scenario Over Canada (Winter 2090)

Figure 5 - CCCma CGCMI Temperature Scenario Over Canada (Summer 2090)

Figure 6 - CCCma CGCMI Precipitation Scenario Over Canada (Winter 2050)

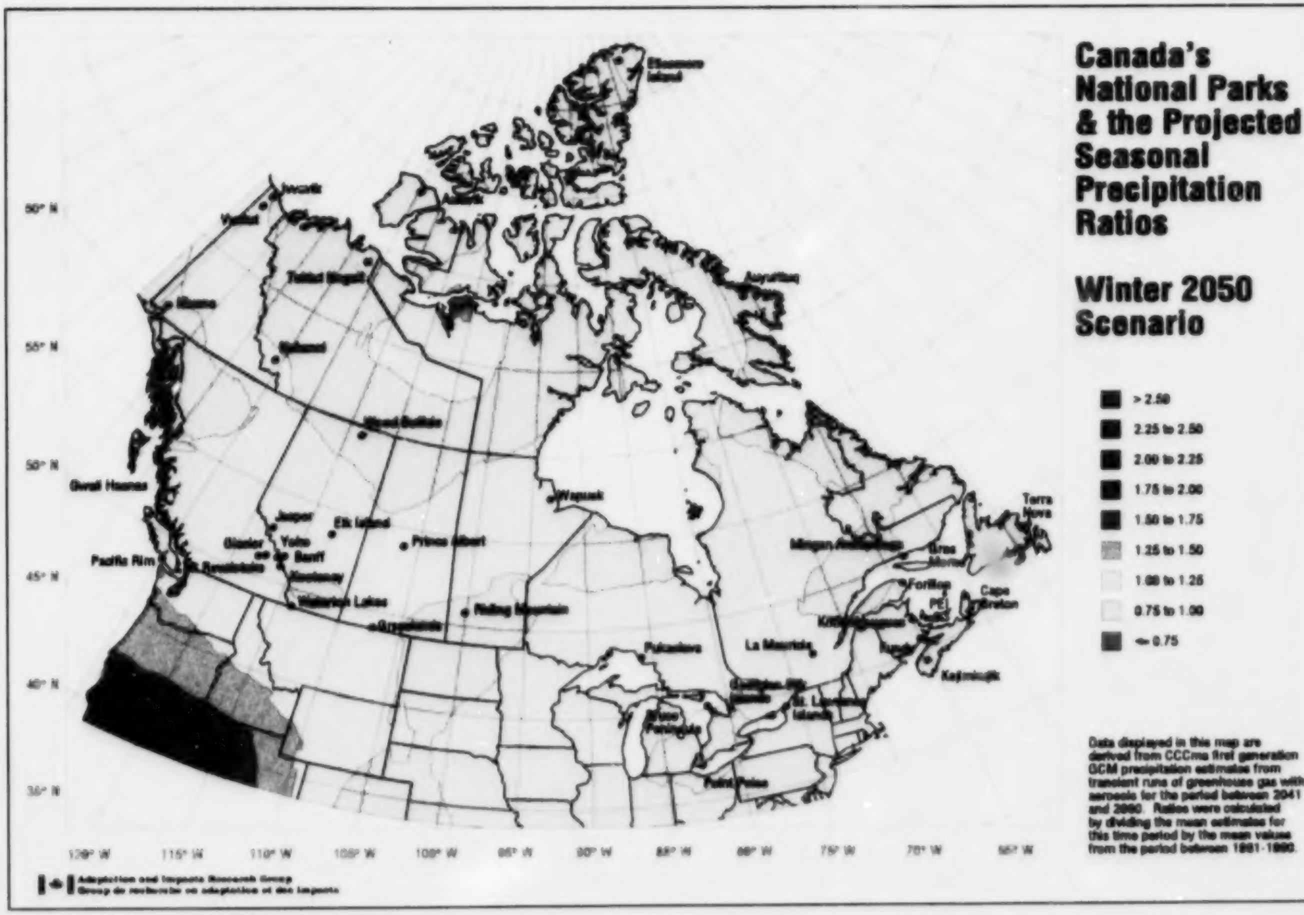


Figure 7 - CCCma CGCMI Precipitation Scenario Over Canada (Summer 2050)

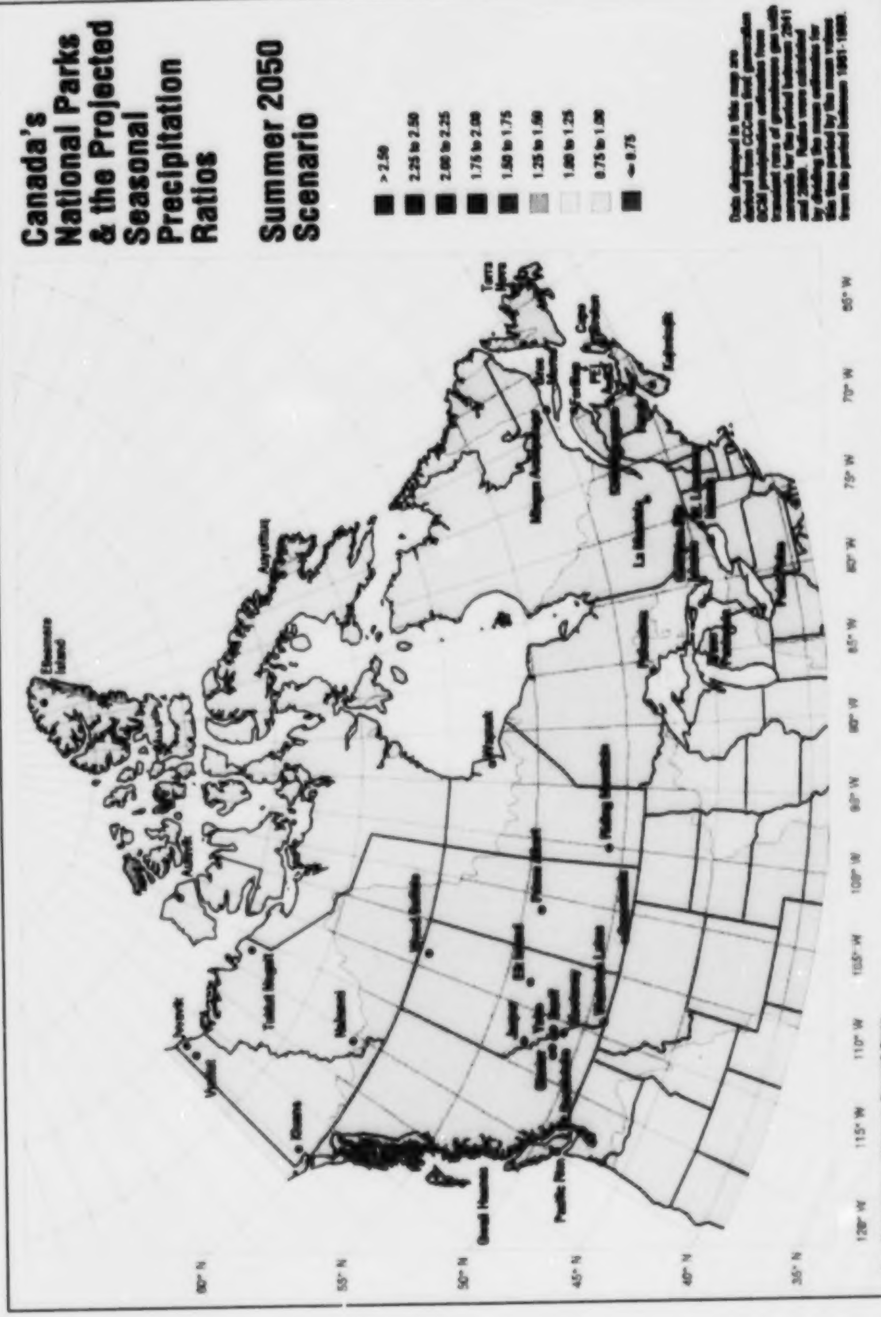


Figure 8 - CCCma CGCMI Precipitation Scenario Over Canada (Winter 2090)

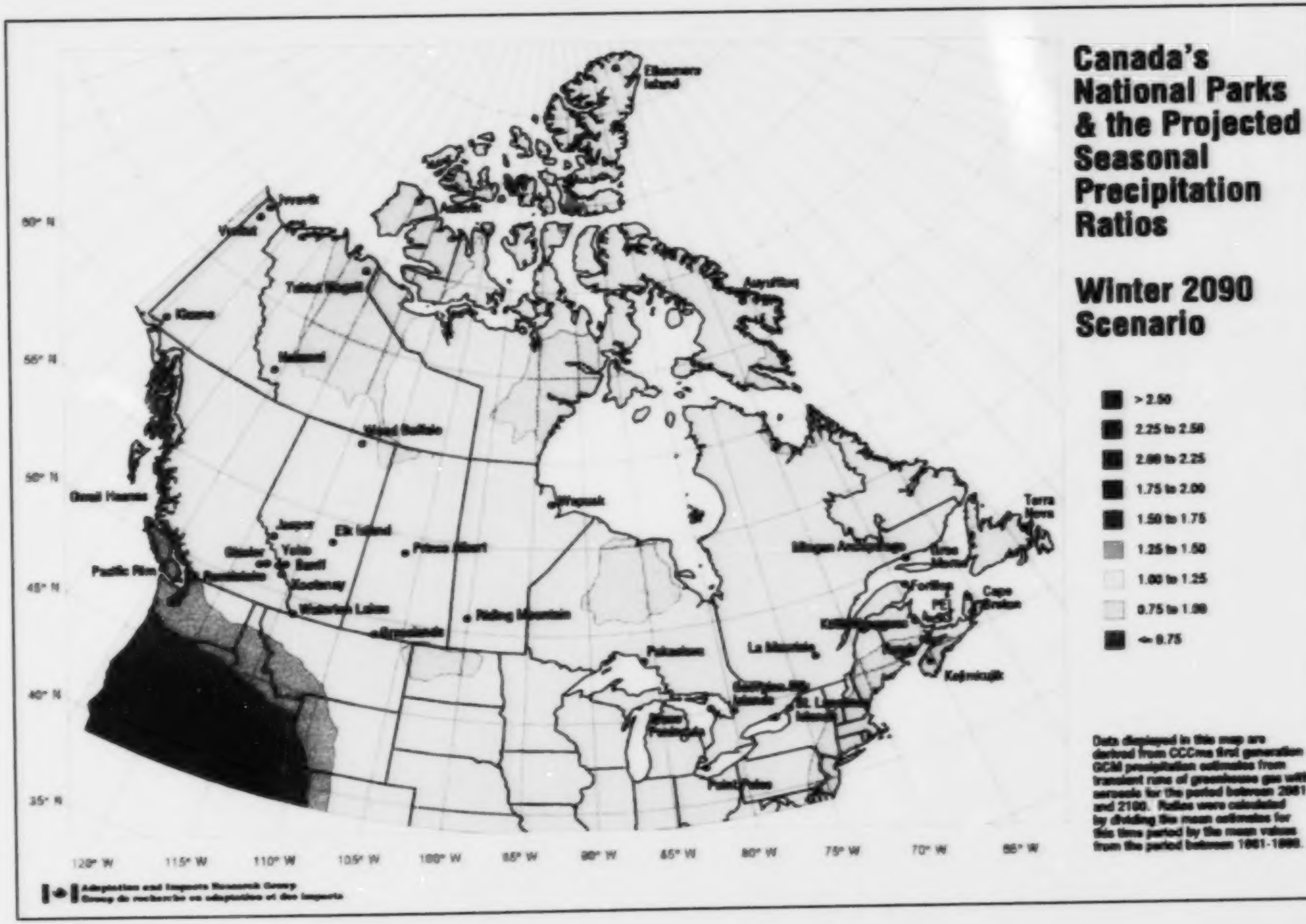
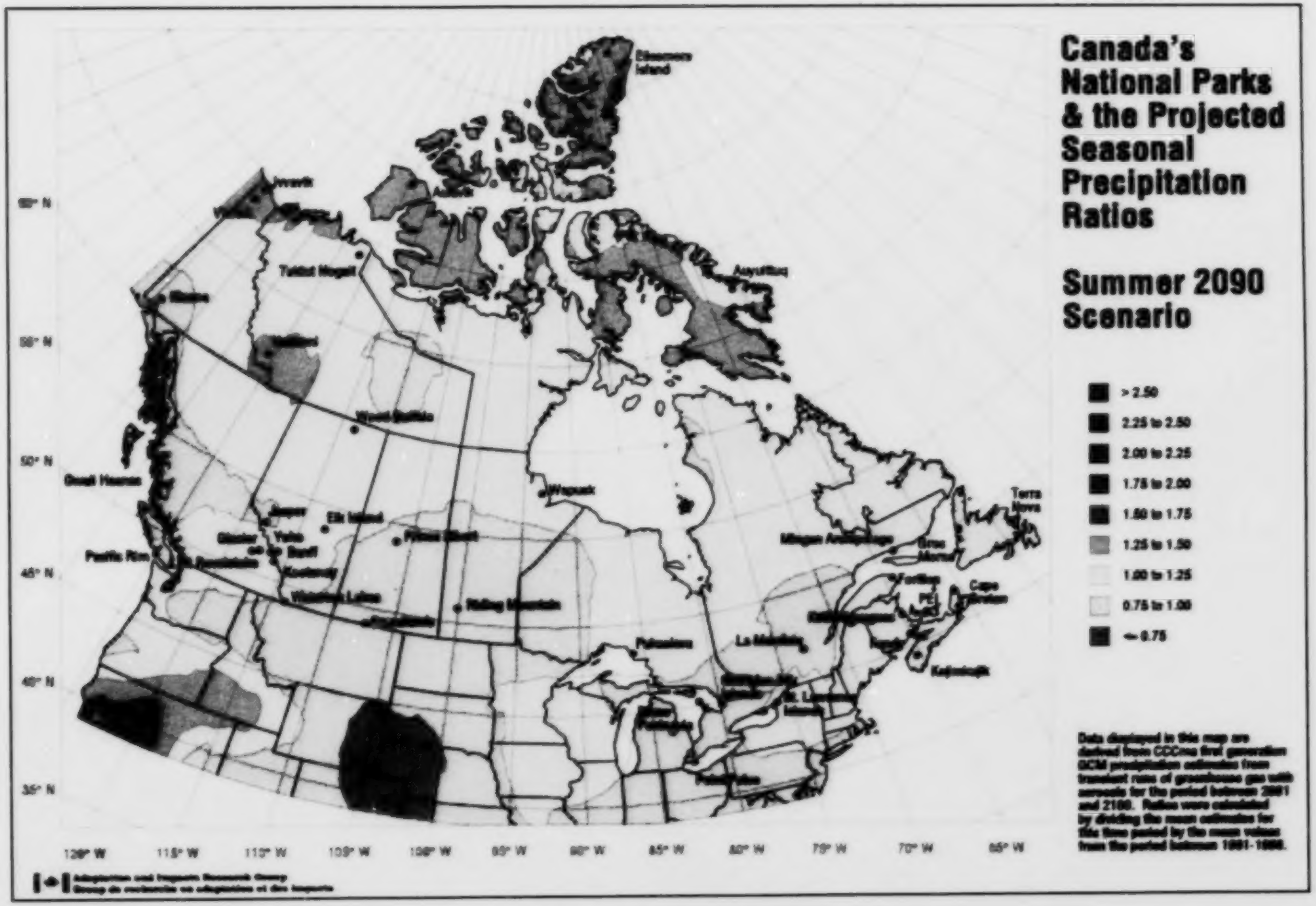


Figure 9 - CCCma CGCMI Precipitation Scenario Over Canada (Summer 2090)



The CCCma CGCM-I winter 2090 temperature scenario for Canada (Figure 4) exhibited spatial patterns similar to the winter 2050 scenario, except with a greater magnitude of change. Most of the continental interior and the Hudson Bay region are projected to warm 6 to 12°C. Some regions of the Arctic are projected to experience stronger warming of up to 16°C. The pattern of summer 2090 warming (Figure 5) is also similar to 2050, with the large majority of Canada projected to warm 4 to 6°C. More pronounced warming is projected for the central Canadian Arctic, while lessor warming of 0 to 4°C is projected for Atlantic Canada.

Projected Precipitation Change in Canada:

It is worth re-emphasizing that precipitation projections from GCMs contain far more uncertainty than temperature projections. There remain discrepancies among different GCMs regarding the magnitude and even direction of seasonal precipitation changes. As such, the reader is reminded to consider the precipitation scenarios with additional caution.

The CCCma CGCM-I precipitation patterns (Figure 6 to 9) appeared more spatially varied. The majority of the country is projected to experience an increase in winter precipitation (100 to 125%). The winter 2050 scenario (Figure 6) did however, project less precipitation (75 to 100%) in areas of Lower St. Lawrence River and far northern Quebec, southern Ontario, parts of the southern and northern Prairies, much of the Northwest Territories, and northern British Columbia. The summer 2050 scenario (Figure 7) has a more distinct pattern, with virtually all of the southern latitudes of Canada experiencing similar to reduced precipitation amounts (75 to 100%). The exceptions to this pattern are the northern and eastern shores of Georgian Bay and the eastern shore of Lake Superior. Areas north of 50° latitude in Quebec and north 60° elsewhere in Canada are projected to experience increased precipitation levels (100 to 125%).

Increased precipitation prevailed for most of Canada in the CCCma CGCM-I winter 2090 scenario (Figure 8). Most of the regions where less precipitation was projected in the winter 2050 scenario were projected to receive 100 to 125% of current precipitation in the 2090 scenario. Two exceptions to this trend are central northern Ontario and large parts of the Northwest and Nunavut Territories. The one area that appears to run against the increased winter precipitation trend for 2050, is the southern half of Nova Scotia, which is projected to receive 75 to 100% of precipitation in the 2090 scenario. Summer 2090 (Figure 9) also reflects increased precipitation for large area versus the 2050 scenario, including much of Atlantic Canada, northern Ontario, Alberta, British Columbia, and most areas of the three northern Territories. The projections for the southern half of Manitoba and Saskatchewan and south-eastern region of Alberta remain less precipitation (75 to 100%).

It is important to note that even in regions where increased precipitation is projected, 'wetter' conditions will not necessarily prevail. With warmer projected air temperatures, increased ice-free conditions and longer growing seasons, the potential for evaporation and evapotranspiration are predicted to increase over much of Canada (Hofmann *et al.*, 1998). In addition, if, as GCMs project, an increased proportion of precipitation comes from fewer, more intense events, there will be less opportunity for soil moisture recharge to take place. These factors are likely to translate into diminished soil moisture and runoff in many areas of Canada; even where moderate precipitation increases are projected (Schindler, 1997; Hofmann *et al.*, 1998). For example, Cubasch *et al.* (1995) predicted that the frequency of three-month drought in central North America would double under $2xCO_2$ conditions.

Extreme Events:

The scenario information provided in this report does not reflect possible changes in climate variability, nor the potential of non-linear responses in the climate system. Beyond projected changes in mean temperature and precipitation levels, analysis of GCM experiments suggest changes in the frequency and/or intensity of extreme climate and weather-related events are also likely as a result of global climate change (Francis and Hengeveld, 1998). Results of GCM experiments suggest a global increase in the frequency of intense precipitation events and the length of dry events (IPCC, 1995b).

GCM results have indicated that under warmer conditions, the amount of moisture transported into middle and high latitudes would increase (Francis and Hengeveld, 1998). Hall *et al.* (1994) and Carnell *et al.*'s (1996) analyses also indicated an intensification and northward shift of storm tracks. A recent North American study (Zwiers and Kharin, 1998), suggested that under 3.5°C global warming conditions, heavy precipitation events could occur twice as often. Lambert (1995) similarly found that the proportion of severe winter storms increased north of 30° latitude under doubled CO_2 conditions.

For many species of flora and fauna, climate extremes are critical. Depending on the length, severity and timing of extreme events, the local and regional ecological consequences could be equally or more important than changes to long-term climate means (Anderson *et al.*, 1998).

Regional Overview of Climate Change in Canada's National Parks:

Narrowing the focus to Canada's national parks, Table 3 displays the CCCma CGCMI projections for winter and summer in each national park, circa 2050 and 2090. It is clear from these scenarios that parks in the six regions will face considerably different challenges from climate change.

Table 3 - Projected Climate Change in National Park Areas (CCCma – CGCMI)

Park	Temperature Change (°C)				Precipitation Change (%)			
	Winter		Summer		Winter		Summer	
	2050	2090	2050	2090	2050	2090	2050	2090
Atlantic								
Cape Breton Highlands	1.7	3.3	1.3	2.2	4%	3%	1%	3%
Forillon	2.5	4.2	1.9	3.8	-3%	10%	2%	7%
Fundy	2.4	3.7	2.4	4.7	9%	4%	-10%	0%
Gros Morne	2.2	3.9	2.1	4.2	-2%	11%	15%	33%
Kejimkujik	1.9	3.4	1.9	3.9	7%	-4%	-5%	-3%
Kouchibouguac	2.4	3.7	2.4	4.7	9%	4%	-10%	0%
Mingan Archipelago	2.3	4.0	1.9	3.8	-1%	10%	-1%	10%
Prince Edward Island	2.3	3.7	2.4	4.6	9%	1%	-7%	0%
Terra Nova	2.4	3.9	2.3	4.8	7%	10%	-3%	15%
Great Lakes – St. Lawrence Basin								
Bruce Peninsula	4.6	6.2	2.3	4.9	-2%	6%	-8%	-13%
Georgian Bay Islands	4.6	6.2	2.3	4.9	-2%	6%	-8%	-13%
La Mauricie	3.4	4.6	2.4	4.8	6%	1%	-7%	-4%
Point Pelee	5.0	7.1	2.6	5.3	-1%	20%	7%	-4%
Pukaskwa	4.9	7.5	2.5	5.0	10%	9%	-3%	-2%
Saint Lawrence Islands	3.3	4.8	2.4	4.9	10%	5%	-7%	-7%
Prairie								
Elk Island	5.0	8.5	2.5	4.4	8%	15%	4%	7%
Grasslands	5.3	7.9	3.1	4.8	15%	20%	-34%	-26%
Prince Albert	5.0	9.3	2.8	4.7	-1%	16%	-10%	-5%
Riding Mountain	5.3	10.5	3.5	5.6	-8%	-13%	-29%	-19%
Wood Buffalo	5.2	8.9	2.7	4.6	-11%	5%	-6%	14%
Western Cordillera								
Banff	3.9	5.7	2.7	4.4	2%	5%	-5%	-1%
Glacier & Mt. Revelstoke	2.8	4.6	2.5	4.3	5%	9%	-6%	-3%
Jasper	3.3	5.2	2.5	4.4	7%	15%	-1%	2%
Kootenay	3.1	4.8	2.6	4.4	2%	5%	-7%	-4%
Nahanni	4.6	7.8	2.6	5.0	24%	40%	51%	95%
Waterton Lakes	3.9	5.7	2.7	4.4	2%	5%	-5%	-1%
Yoho	3.1	4.8	2.6	4.4	2%	5%	-7%	-4%

Table 3 - Continued

Park	Temperature Change (°C)				Precipitation Change (%)			
	Winter		Summer		Winter		Summer	
	2050	2090	2050	2090	2050	2090	2050	2090
Pacific								
Gwaii Haanas	2.1	3.7	2.3	4.2	5%	20%	0%	-3%
Kluane	4.4	7.7	4.2	6.5	0%	11%	0%	-5%
Pacific Rim	2.1	3.7	2.3	3.9	14%	28%	0%	0%
Arctic								
Aulavik	5.5	11.0	5.0	8.7	-18%	-7%	10%	44%
Auyuittuq	5.2	9.7	2.6	5.6	-4%	0%	-4%	29%
Quttinirpaaq	5.9	10.5	4.0	9.2	23%	10%	20%	24%
Ivvavik	5.9	9.2	4.2	6.6	-3%	2%	25%	30%
Tuktut Nogait	4.3	8.5	4.4	7.4	-24%	-10%	0%	22%
Vuntut	5.9	9.2	4.2	6.6	-3%	2%	25%	30%
Wapusk	8.2	11.5	3.8	6.9	16%	11%	9%	12%

With greater projected warming in the continental interior, the magnitude of temperature change is largest for parks in the Arctic and Prairie regions, followed by Ontario, Cordillera and Quebec regions and finally the Atlantic and Pacific coastal regions. For example, the winter 2050 scenario projects Atlantic and Pacific region parks will experience warming of 1.5 to 4°C, while parks in the Prairie and Arctic regions experience warming of 4.5 to 8°C. This inter-regional warming differential is even more pronounced in the winter 2090 scenario.

The pattern of projected precipitation change is more variable than temperature. The majority of national parks are projected to experience precipitation increases in the winter 2050 scenario, with notable exceptions in the Prairie (Riding Mountain and Wood Buffalo) and Arctic (Aulavik and Tuktut Nogait) regions. The trend of greater winter precipitation increased further in the 2090 scenario, with 15 parks projected to experience precipitation increases of 10% or more. Regionally, all of the parks in the Western Cordillera and Pacific regions show increased winter precipitation (both in 2050 and 2090 scenarios). The Atlantic, Quebec and Ontario region parks generally display minor precipitation gains or losses (-5 to +10%) in the winter 2050 and 2090 scenarios. The Prairie and Arctic region parks display greater variability, with respective winter 2050 change in the –10 to +20% and –25 to +25% range.

The pattern of projected summer precipitation change is quite different. In contrast to the winter precipitation gains projected for the majority of parks, in the summer 2050

scenario, 23 of the 38 national parks are projected to receive less precipitation. With the exception of the Prairie region, where projected losses range from –6 to –34%, the projected precipitation decline in all other parks is 10% or less. It is also important to note that the Arctic region parks are generally projected to receive increased summer precipitation; in some cases substantial increases (20% or more in four parks). In the summer 2090 scenario, the number of parks projected to receive less precipitation dropped to 18, only four with declines of 10% or greater (two in the Ontario and Prairie regions). Overall, 19 parks were projected to experience changes of only +-5%. The projected precipitation increase in the Arctic region parks became more pronounced, with all seven parks expected to experience increases of 20% or more.

3.0 Climate Change Impact Assessment

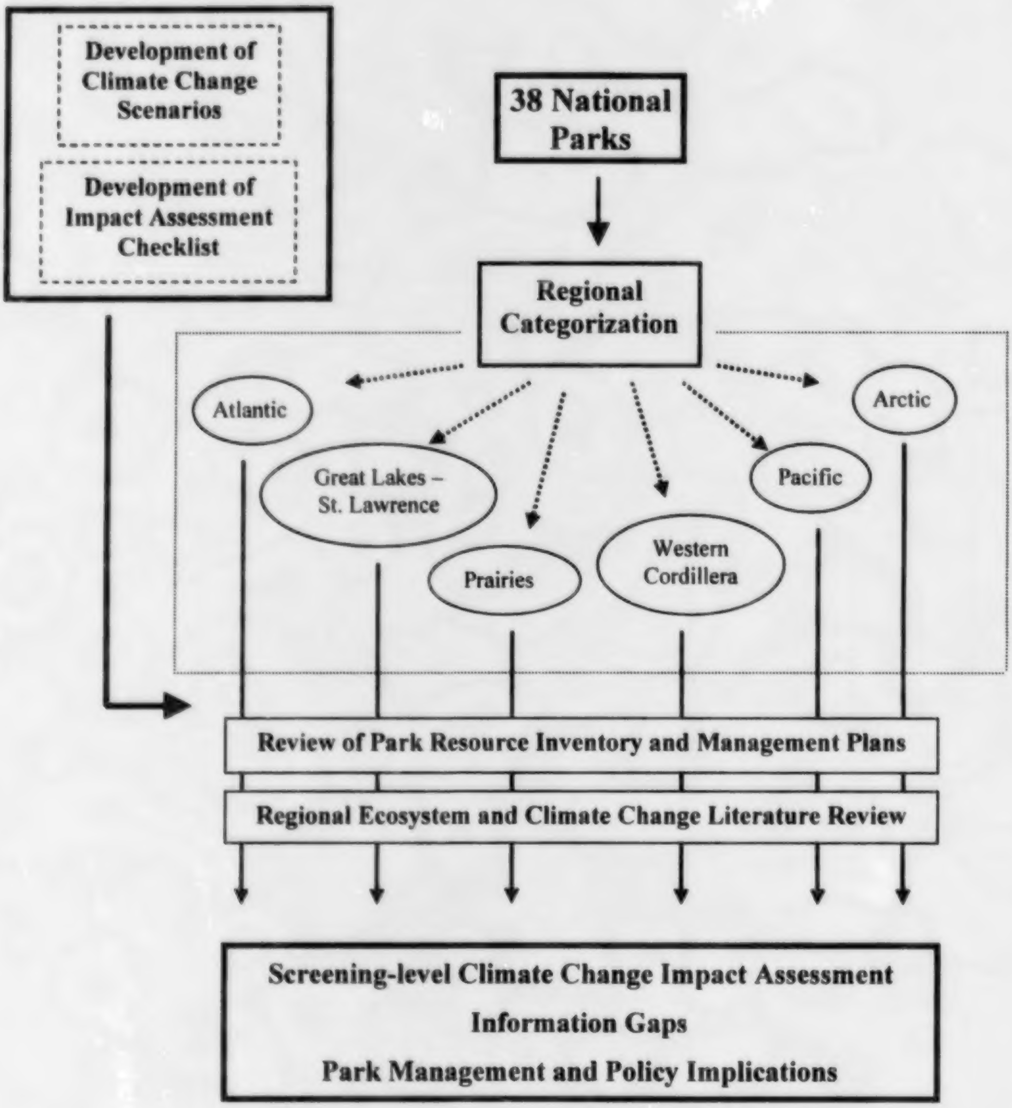
The climate change impact assessment component of the study took place in several phases (Figure 10). At the onset, the 38 National Parks were subdivided into six broad geographic regions (Atlantic, Great Lakes – St. Lawrence, Prairie, Western Cordillera, Pacific, and Arctic) where the range of expected climate change impacts would be relatively similar. This organizational structure was adopted for ease of interpretation, recognizing that parks located near regional boundaries or ecotones could have been classified in more than region.

To ensure consistency across individual park assessments, an impact assessment checklist was developed (Appendix G). The checklist provided a useful, though not exhaustive, list of potential biophysical and socioeconomic variables that may be influenced by projected climate change. The checklist was used to guide the review of park resource inventory and management plans, regional ecosystem literature and relevant climate change studies.

The purpose of this scoping exercise was to identify key issues likely to concern park managers, synthesize the disjointed relevant literature, and to make recommendations for research. It is acknowledged that not all potential ecological impacts have been reflected, nor have all ecosystem inter-relationships been identified and discussed. The implications of climate change for unmanaged ecosystems in Canada remains poorly understood. In addition, data limitations in some parks precluded full discussion of the implications of climate change in these cases.

An overview of the regional cross-cutting climate change impacts introduces each region, a list of the ecological and tourism features, and the range of doubled-CO_2 climate change projections (temperature and precipitation) are provided for each national park. A discussion of potential climate change impacts within each national park follows. For brevity, impacts that effect a number of parks in a region have been discussed in greater length in one park rather than all relevant parks. Readers are therefore advised to review the discussion for all parks in any region of interest.

Figure 10 - Impact Assessment Approach



3.1 Atlantic Parks

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Section 2 indicated that the magnitude of projected climate change in the Atlantic region was less than the rest of Canada. There are however, likely to be important climate change related impacts for national parks in this region as a result of altered ocean conditions. Global climate change is projected to result in sea-level rise in the order of 0.5m over the next century. Sea-level rise will be exacerbated on Canada's Atlantic coast by continental subsidence of approximately 0.3m per century. With the possible exception of the Beaufort Sea coastline, climate change related sea-level rise would have greater ecological consequences in this region than elsewhere in Canada.

Shaw *et al.*'s (1998) study of the sensitivity of the Canadian coastal areas to projected sea-level rise, indicated that the likelihood of physical changes in the coastal zones of Kejimkujik, Kouchibouguac and Prince Edward Island National Parks was high. The sensitivity of coastal areas of Cape Breton, Fundy, Gros Morne, and Mingan Archipelago National Parks were rated as moderate. Forillon and Terra Nova were the only Atlantic coastal parks with low sensitivity. Shaw *et al.* (1998) did not examine the ecological or socio-economic sensitivity of the coastal areas to sea-level rise, and the former remains an important area of research for the Atlantic Region national parks.

The net effect of these changes will have implications for the marine-terrestrial interface, including increased coastal erosion; salinity changes; and altered marine, dune, tidal pool, salt marsh and estuary habitats. The potential for increased storm intensity could mean extreme events might have a larger ecological role in the national parks of this region in the coming century. The role of changes in ocean currents and water temperatures remains an important uncertainty.

The potential for less harsh conditions and invasions by southern exotics (both flora and fauna) may diminish the region's boreal forests and reduce or alter the relict arctic-alpine assemblages in Forillon and Mingan Archipelago National Parks.

3.1.1 *Cape Breton Highlands National Park*

Cape Breton Highlands National Park			
DATE ESTABLISHED	1936		
LOCATION	Nova Scotia – Park Geocentroid: 46.69°N, 60.81°W		
SIZE	948 km^2		
FEATURES	• Maritime Acadian Highlands Natural Region • Highland barrens and bogs • Rare arctic and alpine plants • Steep headlands, rocky beaches • 15 rare and endangered native mammal species • Nesting shorebirds: puffins, gannets and terns		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	-2.0 to +19.0
SUMMER	+1.0 to +4.0	SUMMER	-26.0 to +7.0
FALL	+2.0 to +4.0	FALL	0.0 to +13.0
WINTER	+2.0 to +5.0	WINTER	+4.0 to +24.0

Cape Breton Highlands National Park (CBHNP) is marked by plateaux and steep cliffs that meet the sea. CBHNP has one coast facing east to the open Atlantic while the other is more sheltered and faces west to the Gulf of St. Lawrence. The park is also characterized by extensive hills and valleys covered with stands of hemlock, red maple, white birch and red spruce trees. There are also bogs and subalpine habitat on the tops of the plateaux in the park. The area of Cape Breton Island and the park have been logged several times in the past (Parks Canada, 1994a).

Climate change scenarios project a relatively even increase in temperature in the CBHNP area throughout the year. Precipitation is expected to increase in the winter and fall. Projections of future climate change suggest sea-level could increase at a rate of 1 to 2 mm/year. By the year 2100, an increase of 0.5m is expected in Atlantic Canada (Forbes *et al.*, 1997). Crustal subsidence will magnify the effects of sea-level rise in the area.

Shoreline sensitivity to sea-level rise is considered moderate on the west shore and low on the high rocky headlands of the east shore (Shaw *et al.*, 1998a). The barrier complex at Aspy Bay will probably be either permanently inundated or become a low marsh environment. Coupled with an expected increase in storm frequency and intensity (Forbes et al., 1997), it is expected that the coastal profile of CBHNP will be altered by increased flooding of coastal areas and erosion of coastal bluffs. With average winter temperatures projected to increase from –4.1°C to –2.1°C to +0.9°C, it is also probable that the period of sea and shore ice will be reduced. This would increase the exposure of the shoreline to winter storm energy and further enhance erosion along the coast (Forbes *et al.*, 1997).

Wetlands in the Atlantic coast area will be impacted if there is a change in the regional climate. Temperature increases coupled with increased rates of evaporation could negatively impact wetlands (Clair *et al.*, 1997). Clair and Ehrman (1996) indicate that an annual temperature increase of 3°C could lead to a 29% decrease in regional river discharge fed by wetlands. It is unknown how this change in water levels will affect wetland distribution in the Atlantic region and in the area of CBHNP (Shaw, 1997).

The composition of ecosystems in CBHNP may be altered by climatic change. Ironwood trees are rare in the Cape Breton region of Nova Scotia and are at the northern end of their range in CBHNP. This species will likely benefit from projected temperature increases in the region. Conversely, arctic-alpine plants, such as dwarf birch trees and bog plants, at the southern end of their range, would be reduced or disappear under conditions of global warming.

Other environmental changes associated with global climate change will also have implications for the forests of CBHNP. A warmer climate in the region could lead to an increase in the rate of growth for conifers due to an increased nutrient availability in warmer soils (Cox, 1997). Expected increases in storms could increase damage to forest stands in the area of the park (Forbes *et al.*, 1997) and conversely favour the transition from a boreal forest stand to a more temperate mixed forest. A warmer climate would be conducive to the spread of balsam woolly adelgid and beech bark disease in CBHNP (Cox, 1997). The risk of forest fire is projected to increase only slightly due to climatic change (Bergeron and Flannigan, 1995), however this projection could be effected by blowdowns and insect outbreaks that can increase the quantity of fuel available (Cox, 1997).

Individual fauna species in CBHNP will experience disparate impacts associated with the aforementioned habitat changes. The range of certain fauna is likely to change depending on habitat needs and ecosystem changes. Coupled with fires, warmer winters would increase the amount of food available for such species as moose, while decreasing regeneration of various tree species through browsing (Cox, 1997). Warming is likely to impact migratory bird and resident bird populations in the park. Boundaries for winter bird populations are expected to shift northwards. Research is still needed to determine the exact relationship between distribution of bird species and the climate during the summer (Clair *et al.*, 1997). Flooding and increases in the sea-level will impact shorebirds and waterfowl migrating between their breeding grounds and winter habitats. The impact of climate change on populations of pilot whales, bald eagles and shellfish in CBHNP remains uncertain.

With warmer winter temperatures, a shorter winter recreation season and disruptions in winter activities, including downhill skiing (at Cape Smokey) and cross-country skiing can be expected. The anticipated 4 to 24% increase in winter precipitation, may lead to higher snowfall and improved conditions during the winter recreation season.

Warmer spring and fall temperatures may extend the season length of summer recreation activities, with the economic benefit of an extended golf season. There is some evidence to suggest that warmer summer temperatures will translate into increased numbers of domestic park visitors (Wilton and Wirjanto, 1998). The slight increase in forest fire risk would not likely require a review of the park's open fire policy or increase the number / length of open fire bans substantially. The potential impact of increased visitation and recreation fees (e.g., golf and camping) for park revenue remains to be examined.

3.1.2 Forillon National Park

Forillon National Park	
DATE ESTABLISHED	1974
LOCATION	Québec – Park Geocentroid: 48.88°N, 64.42°W
SIZE	245 km^2
FEATURES	• Notre Dame and Megantic Mountains Natural Region • Geomorphological diversity consisting of steep, rocky cliff, beach, plain, and a low-lying sandspit area • Boreal forest covered highlands • Abundance of marine birds and mammals

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	+3.0 to +23.0
SUMMER	+2.0 to +3.0	SUMMER	-12.0 to +5.0
FALL	+2.0 to +3.0	FALL	-3.0 to +13.0
WINTER	+2.0 to +7.0	WINTER	-3.0 to +24.0

The coastal and marine zone of Forillon National Park provides a dynamic environment in which a range of potential climate change impacts may occur to the ecological processes and features of the park. The combined effects of relative sea-level rise (0.5 m by 2100) and increased storm severity (Abraham, 1997; Forbes *et al.*, 1997) have the potential to influence flood risk, coastal erosion and sediment redistribution, and salinity in coastal ecosystems. Overall, the sensitivity of the Forillon area shoreline to physical changes from a rising sea-level is low (Shaw *et al.*, 1998a).

Currently, few parts of the coast at Forillon National Park are directly affected by wave action, as most of the coastal escarpments are protected by beaches or boulder piles (St. Amour, 1985). Increased sea-level rise in conjunction with an increase in the number of intense storms could increase the rate of erosion and resulting sedimentation in the coastal zone. The north and Northeast facing shores of the park are the most sensitive area as waves driven from the north and north-east have significant fetch and erosive power, with consequent implications for the transport of sediments along the Presqu'ile Forillon to the Southeast beach at Penouille. With projected sea-level rise, the narrow sandy ridge linking Penouille spit to the mainland could be breached in storm conditions (Shaw *et al.*, 1998a). Changes to the freeze-thaw action that fractures the cliff-face rocks, facilitating

the erosion process, must be considered. Winter temperature increases projected for the park could influence the intensity and/or duration of the freeze-thaw process, potentially reducing coastal erosive capacity. Climate change and associated changes in marine currents may also influence the large expanses of wind and tide driven ice floes moving along the coast in winter. Less ice and decreased stability of the ice would alter the coastal deposition and erosion processes, as well as decrease the protective action of sea ice during intense winter storms.

Sea-level rise and changes in the erosion-sedimentation balance, may impact low-lying features in the park. These features include the sand dune and sandspit formation at Penouille, as well as the adjacent salt marsh and salt meadow. The salt meadow and its organisms are adapted to occasional inundation by seawater. An increase in salt-water inundation frequency and duration as a result of sea-level rise or greater storm severity would influence the species composition. Similarly, ecological productivity may be radically affected by changes in the frequency and duration of seawater inundation. Changes in salinity and/or the erosion/sedimentation balance may also change or destroy this ecosystem. For example, vegetation-free salt marsh pannes could become saltier in summer through increased evaporation, and thus expand in area. Thus a unique ecological feature, identified for special preservation in the park (Parks Canada, 1994b; 1995a) could be at greater risk.

The changes described above may be further exacerbated by impacts of projected temperature increases throughout the year. For example, the dune vegetation at Penouille has adapted to the harsh conditions imposed by sandy, poor soil and coastal climate. Such conditions are similar in some respects to those of the taiga, and as a result, there are unique taiga assemblages composed of specially adapted black spruce, 36 species of lichen, club mosses, heath, and pioneer plants like false heather (St. Amour, 1985). A warming trend could negatively influence this relict taiga vegetation in the park.

Approximately 30 rare and valuable relict species (e.g., saxifrage, sedges, Whitlow grass) of the arctic-alpine communities on exposed, rocky cliff faces (Lefebvre, 1983) are also likely to be impacted. Most arctic-alpine species benefit from pioneer successional conditions (especially relicts in the south of their range) (St. Amour, 1985); therefore, increased cliff erosion could be beneficial. However, these species may experience physiological stress as a result of warmer and drier summer conditions. Indeed, their success is partly due to the short summers and limited growing season in the region. These vegetation communities do not tolerate competition from other pioneering species and any changes in productivity, growth, and colonization of other species would influence the viability of these unique assemblages.

In contrast, outliers of forest and understorey vegetation of the Laurentian maple association that are located within the boreal forests of the park may benefit from warmer conditions. For example, small groupings of oak, elm, and ash, and bloodroot are present (St. Amour, 1985). These relict assemblages are typical of earlier periods when the climate was warmer, and may expand with anticipated increases in temperature.

Disturbance from disease and insects will also likely increase with warmer temperatures (Cox, 1997). Lenihan and Neilson (1995) project a shift from the boreal evergreen communities to a more temperate summergreen forest in the area.

Sea-level rise and changes to seawater properties may also influence valued park fauna. Depending on the amount of sea-level rise, marine mammals such as gray seals and harbour seals may lose specific habitat (e.g., island-like rock outcrops off the north shore or the flat rocks of the northern coast that have fallen from cliff faces - see Parks Canada, 1994b, 1995a). In addition, the Gaspé current plays an important role in marine productivity around the park by circulating warmer water from the St. Lawrence River (i.e., summer water temperatures around Forillon are approximately 10°C warmer than those that pass the Mingan Archipelago (St. Amour, 1985). Projected cooling of the Labrador current may decrease water temperatures around Forillon National Park (Clair, *et al.*, 1997). This could affect marine productivity, with associated influences on food chains supporting marine mammals and seabird colonies.

The potential impacts of climate change (e.g., sea-level rise, terrestrial temperature increase, etc.) on infrastructure and visitor experience are likely to be limited. Depending on the extent of relative sea-level rise, the unique habitat and infrastructure associated with the low lying Penouille area of the park could be negatively affected (e.g., trails, picnic areas, beaches, etc.). Changes in sea temperature and marine productivity may influence whale populations, and therefore, whale watching activities. Extra fog resulting from terrestrial temperature increases and marine cooling may limit the number of days on which whale watching excursions can occur. The length of the season for summer recreational pursuits such as hiking, camping and mountain biking would increase with warmer temperatures. Winter recreation may be limited by a shorter season, although higher precipitation combined with mean winter temperatures of (-3°C to –8°C) could result in better snow conditions.

3.1.3 Fundy National Park

Fundy National Park			
DATE ESTABLISHED	1948 (officially opened in 1950)		
LOCATION	New Brunswick – Park Geocentroid: 45.65°N, 65.10°W		
SIZE	207 km^2		
FEATURES	• Maritime Acadian Highlands Natural Region • Inland zone composed of streams, wetlands, and Acadian forests • Irregular coastal zone dominated by nearly perpendicular rocky cliffs and deeply incised valleys • Mudflats, salt marshes and tidal pools exposed and submerged by the giant tides of the Bay of Fundy • Identified climate change as an important ecological stressor in 1997 State of the Parks Report		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	+1.0 to +19.0
SUMMER	+2.0 to +4.0	SUMMER	-19.0 to +12.0
FALL	+2.0 to +4.0	FALL	-9.0 to +12.0
WINTER	+2.0 to +5.0	WINTER	+7.0 to +19.0

The ecological structure and function of Fundy National Park is closely linked to the tremendous tides of the Bay of Fundy and their associated effects. Along the coastal portion of the park, the average tidal range is 9m, with a spring tide range of over 13m (Burzynski, 1985). The combined effects of relative sea-level rise (0.5m by 2100) and continental subsidence in the region (0.3m/century) have the potential to influence geomorphological and ecological processes in Fundy National Park, including increased flood risk, accelerated coastal erosion, and sediment redistribution (Forbes et al., 1997). While the lower and middle portions of the park coastline are comprised of resistant rock, the upper portions of the park coastline are comprised of erodable, soft conglomerates, sandstone and shale. Sea-level change will likely increase erosion at the base of the cliffs, allowing them to be more deeply cut and increasing their instability. The sensitivity of the park shoreline to sea-level rise was classified as low to moderate by Shaw et al. (1998a). The tidal flats at Alma Beach and salt marshes at the mouths of the Upper Salmon, Point Wolfe and Goose Rivers are likely to be the most sensitive areas.

Closely associated with coastal dynamics are a myriad of tidal pools, mudflats and salt marshes (e.g., Alma Beach). At present, the tides have a range of important physical and biological effects on the waters and intertidal areas of the park, including vertical mixing of water, mixing of sea water and freshwater in estuaries, and providing exposure to large areas of the intertidal region (Woodley, 1985). As a transition zone between the terrestrial and marine environments, there is a range of organisms that possess limited tolerance to seawater inundation. The impact of sea-level rise and change in tidal action, sediment

transfer and deposition on this transition zone remains uncertain. It is likely however, that the productivity of this zone will be altered. This has important implications for the many marine and terrestrial species that rely on this zone, especially migratory birds using the mud flats and salt marshes as stopover zones (Woodley, 1985; Burzynski, 1985).

Some researchers suggest the Labrador current will become colder and extend further south along the coast as the Greenland ice cap melts (Clair et al., 1997). The marine region of Fundy National Park is a transition zone between cold-water organisms of the lower bay and a number of endemic warm-water organisms of the upper bay that have been cut off from parent populations (Woodley, 1985). Cooling marine influences associated with climate change in the Atlantic region may therefore have a more pronounced impact on the warm-cold water species composition in the Fundy National Park area. For example, a few coldwater seabirds, including the black-legged kittiwake (which colonized the Bay of Fundy in the late 1980's) and the razorbill (which recently established a new breeding site in the Bay of Fundy - (Mawhinney and Sears, 1997), may continue to expand their breeding range southwards.

Natural climate events (e.g., wind damage, salt spray up to several kilometres inland, etc.) have had a pronounced and long-term effect on park vegetation. The potential for increased storm intensity in the region, (Abraham, 1997; Goldenberg et al., 1997), may change vegetation dynamics. A reduced return period may diminish the capacity of vegetation to recover from weather disturbances. In addition, disturbance from disease and insect pests such as the spruce budworm will likely increase with warmer conditions (Cox, 1997). When combined with other ecological stresses, existing successional trajectories may be altered. Ecological structure will also likely be altered by an increase in the frequency and severity of fires in boreal forests (Stocks et al., 1998; Suffling and Speller, 1998). The rare Bird's-eye Primrose, found only in Fundy National Park, is a cliff-dwelling plant remnant of a colder climate which may become further threatened by increases in temperature and changes in physical conditions resulting from climate change. Ungulates may be affected by changes in snow pack resulting from higher winter precipitation (assuming it comes in the form of snow). Browse may become more difficult to access, increasing winter hardship on moose and deer.

Sea-level rise, increased precipitation, erosion and loss of bank stability, may influence management and use of park trails, as well as other recreation infrastructure. While this is a generic problem in many regions, the steep stream valleys and edges in Fundy National Park are not amenable to trail construction and maintenance (Woodley, 1985). Moreover, stream water levels can rise rapidly after a storm. Park managers will therefore need to review safety strategies to address thc threat of floods. The length of the season for summer recreation pursuits, such as hiking and camping, should increase at the expense of the season for winter recreation. If increased winter precipitation falls as snow, the conditions may be improved for activities such as cross-country skiing, despite the shortened season.

3.1.4 Gros Morne National Park

Gros Morne National Park	
DATE ESTABLISHED	1970 (amended 1973, 1978, 1983)
LOCATION	Newfoundland - Park Geocentroid: 49.82°N, 57.80°W
SIZE	1,805 km^2
FEATURES	• Western Newfoundland Highlands Natural Region • Designated a UNESCO World Heritage site • Characterized by unique geological features, a mountainous zone rising from a narrow coastal plain, and a vast alpine plateau of tundra, bogs and 'tuckamoor'

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	-1.0 to +20.0
SUMMER	+2.0 to +4.0	SUMMER	-9.0 to +15.0
FALL	+2.0 to +4.0	FALL	+3.0 to +18.0
WINTER	+2.0 to +7.0	WINTER	-2.0 to +16.0

Gros Morne National Park (GMNP) can be divided into two broad biogeographic zones, the coastal plain zone and the upland zone of the Long-Range Mountains. Both zones provide a dynamic environment sensitive to a range of projected climate change impacts. The mountain zone is also divisible into distinct acid rock and ultra-basic rock landscapes, each with distinct flora.

The relatively flat terrain of the coastal plain is typically covered with raised peat moss (sphagnum) and reindeer lichen bog formations, which are often comprised of tufted club rush, bake apple, black crowberry, and insectivore plants. Much of this zone is comprised of 'tuckamoor,' a wind-derived, low-lying vegetation assemblage consisting of twisted thickets of balsam fir and white spruce (Parks Canada, 1997a). While these vegetation communities are adapted to the growing conditions of the coastal plain, changes in sea-level may result in more frequent inundation, a raised water table, or an increasingly saline water table. Although certain tuckamoor assemblages located closer to the shore are occasionally inundated with seawater (Bouchard, 1975), an increase in inundation frequency and/or duration that could result from increased water levels may be deleterious to this assemblage. Shaw *et al.* (1998a) classified the sheltered fjord inlet of Bonne Bay as having low sensitivity to sea-level rise, while much of the remaining coast was rated as moderately sensitive. Areas at risk include the barriers, lagoons, coastal dunes, tidal flats and marshes at St. Paul's inlet.

The role of projected precipitation increases and associated run-off in this coastal zone must also be considered, particularly in seepage zones behind the coastal plain (see Bouchard, 1975). Bogs are typically nitrogen-poor environments and increasing levels of

nitrogen rich run-off into the bog environments may lead to structural and functional changes. In turn, alterations in habitat quality, food availability and distribution may influence seabirds nesting along the coastal plain of Gros Morne National Park. This is of particular concern as this zone provides important habitat for common tern, great black-backed gulls and herring gulls (Bouchard, 1975; Beardmore, 1985). With limited projected climate warming, changes in water temperature should not be so substantial as to affect the distribution of the 11 species of fish in the streams and wetlands of GMNP.

Projected temperature and precipitation increases in Gros Morne National Park also have the potential to influence the tundra-like vegetation of the upland alpine plateau. The vegetation in this zone of the park is a direct result of cool temperatures associated with the exposure and drying winds of the elevated plateau (Beardmore, 1985). The ultra-basic rocks of the table mountain range limits tree growth. These vegetation communities benefit from lack of competition from pioneering species of less basic soils. Indeed, their success is partly due to the short summers and limited growing season in the region. Any changes in productivity, growth, and colonization by other species could influence the viability of these unique assemblages. Considering the projected increases in temperature and precipitation, growing conditions for other pioneering species may develop. In addition, disturbance from disease and insect pests will likely increase with warmer conditions, altering the patch dynamics of forest stands (Cox, 1997). The influence of these changes on local caribou populations, which feed on the extensive patches of lichens, is unclear. As mentioned in section 3.1.1, changes in winter precipitation may increase hardship for ungulates such as caribou and moose by limiting mobility and access to browse.

The potential adverse impacts of climate change on infrastructure and visitor experience in GMNP is generally limited. Warmer temperatures would extend the summer tourist season somewhat for popular recreation activities such as hiking, camping, kayaking, sightseeing and beach use. Increased winter precipitation could result in better snow conditions for snowmobiling and cross-country skiing, although for a shortened season. The net effect on park revenues remains uncertain. Finally, depending on the extent of relative sea-level rise, park infrastructure (e.g., roadways, trails, picnic areas) located in the coastal zone could be negatively affected.

3.1.5 *Kejimkujik National Park*

Kejimkujik National Park	
DATE ESTABLISHED	1974 (shoreline adjunct in 1985)
LOCATION	Nova Scotia – Park Geocentroid: 44.37°N, 65.33°W
SIZE	381 km²
FEATURES	• Atlantic Coast Uplands Natural Region • Region of interconnected lakes, streams and low rolling topography • Mixed wood forests of spruce, pine, oak and maple in Atlantic Coast Upland Region • Extensive brackish ponds and broad tidal flats associated with the seaside adjunct

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	0.0 to +19.0
SUMMER	+2.0 to +4.0	SUMMER	-19.0 to +16.0
FALL	+2.0 to +4.0	FALL	-12.0 to +10.0
WINTER	+2.0 to +4.0	WINTER	-3.0 to +19.0

Kejimkujik National Park is comprised of two distinct areas, an upland terrestrial zone and a marine-influenced seaside adjunct. Projected sea-level rise will likely effect coastal processes along the seaside adjunct of Kejimkujik National Park. Given the combined effects of relative sea-level rise (0.5 m by 2100) and continental subsidence in the region (0.3 m/century), increased flood risk, accelerated coastal erosion, and sediment redistribution are likely (Forbes *et al.*, 1997). The coastline at Kejimkujik National Park is classified as a highly sensitive to climate change (Shaw *et al.*, 1998a). The brackish ponds, lagoons and broad tidal flats may suffer inundation and extra sedimentation, while sparsely vegetated sandspits and beaches may become increasingly vulnerable to severe storms, both through wave action and wind erosion. The effects will vary with wave height and angle of approach, as well as wind direction.

Changes to sandspit beaches and tidal flats are of concern as they provide essential habitat for migratory shorebirds, including the endangered piping plover (Drysdale *et al.*, 1992; Corbett 1997). There is limited nesting habitat outside of Kejimkujik, Kouchibouguac and Prince Edward Island National Parks for this species and additional stress associated with climate change impacts could further impair breeding success. Sea-level rise could inundate nesting beaches, especially where they are backed by higher ground (Herman and Scott, 1994). Enclosures to increase nesting success of piping plover initially developed at Kejimkujik National Park could also be negatively affected.

A 0.8m rise in sea-level could cause an inland retreat of the freshwater water table. As a result, successional processes may change and plant species distributions altered.

Inland, the interconnected lakes, streams and low rolling topography of the park's terrestrial component support mixed-wood forests of red spruce, white pine, red oak and red maple. The potential impacts of climate change for inland areas will differ significantly from those expected in the seaside adjunct. While the extent to which reduced summer rainfall (as projected by three of four GCMs) and increased temperatures will alter natural disturbance processes is unclear, change is likely (Suffling and Speller, 1998; Stocks *et al.*, 1998). The moderate climate of the region may be the reason for the existence of some rare flora and fauna in the park (see Drysdale *et al.*, 1992). Further climate moderation will likely support the vigour of these rare, generally southern, species.

The combined influences of fire and wind play an important role in the successional vegetation processes in the park (Parks Canada, 1997a). An increase in forest fire intensity and frequency would promote a shift from conifers to hardwood species. Early successional systems, such as the red oak – red maple – white birch forest could expand with greater disturbance from fire, insects and disease (Cox, 1997). Overall, Gomer (1999) identified a potential positive response to climate change in red maple and poplar, but a negative response in red spruce, maple, hemlock, beech, white ash, Plymouth gentian, pink coreopsis, redroot, golden crest, and water pennywort. Animal species dependent on mature forest (e.g., American marten) will likely be negatively impacted by climate change, while species more tolerant of disturbed areas (e.g., grey squirrel and brown-headed cowbird) could benefit (Gomer, 1999).

Clair *et al.* (1998) predicted peak runoff in the Atlantic Maritime region would change from May to April and the month of minimum flow would shift from September to August. These changes in run-off could alter the structure and function of the park's naturally shallow, oligotrophic and acidic lakes (Drysdale *et al.*, 1992). Park waters are acidic because of the abundance of wetlands which typically generate natural organic acids (Clair and Drysdale, 1992). In turn, these encourage organisms such as brook trout to adapt to these naturally acidic waters. The extent to which water quality in the park may be influenced by changes in precipitation and run-off is unclear. The vulnerability of Blanding's turtle is a concern however, given the highly isolated disjunct population in Kejimkujik and its threatened designation by COSEWIC (Herman and Scott, 1994; Morrison, 1996). The turtle's narrow biophysical needs (i.e., highly coloured acidic waters, and specific substrate and exposure requirements) and small population (less than 200 adults), make it particularly vulnerable to changes in water quality, water level and insolation associated with climate change (Herman and Scott, 1994). In general, turtle sex ratios are affected by egg incubation temperature. Consequently, climate change is likely an important issue for turtle populations overall.

The unique aquatic conditions of the park have also provided 'calibrated lakes' for Environment Canada's Long Range Transport of Air Pollutants research initiative (Kerekes, 1992). Increased run-off and a warmer climate are likely to influence the effect of acid precipitation in park lakes.

Potential impacts associated with climate change and variability are not expected to significantly affect park visitor use in either the terrestrial or seaside adjunct of Kejimkujik National Park. Decreased summer water levels could effect the navigability of some popular canoeing venues in the park and increase requirements for summer portages. Sea-level rise and associated erosional changes could influence visitor use of beach areas (e.g., loss of access or beach area) and threaten park infrastructure (e.g., boardwalks, parking lots). Cooling of the Labrador Current and rising terrestrial temperatures could cause more coastal fog, possibly discouraging summer visitation along the marine portion of the park. Visitor access to beaches may need to be better controlled, as plover habitat becomes more restricted.

3.1.6 Kouchibouguac National Park

Kouchibouguac National Park			
DATE ESTABLISHED	1979		
LOCATION	New Brunswick – Park Geocentroid: 46.82°N, 64.97°W		
SIZE	239 km^2		
FEATURES	• Maritime Plain Natural Region • Area of flat, low-lying terrain • Principal ecosystems in the Park include salt marshes, estuaries and lagoons, offshore barrier dune systems, as well as bogs, cedar swamps and various successional forest assemblages • Supports habitat and nesting grounds for range of shorebirds		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+1.0 to +4.0	SPRING	+1.0 to +19.0
SUMMER	+2.0 to +4.0	SUMMER	-10.0 to +7.0
FALL	+2.0 to +4.0	FALL	-9.0 to +13.0
WINTER	+2.0 to +5.0	WINTER	+7.0 to +24.0

Projected sea-level rise of 0.5m by 2100 in combination with subsidence in Atlantic Canada of 0.3m per century (Forbes *et al.*, 1997) and increased storm intensity and frequency are expected to influence coastal processes in Kouchibouguac National Park. Increased flood risk, accelerated coastal erosion, and salt water inundation are likely impacts. Shaw *et al.* (1998a) classified this shoreline as highly sensitive to change from sea-level rise. Key geomorphological and hydrological features in the park, including the sensitive 26 km long barrier island dune system, salt marshes and lagoon ecosystems, may experience significant impacts (Canavan, 1997).

The park's sparsely vegetated barrier island dune system may become increasingly vulnerable to severe storms and associated wave action resulting in inundation, a loss of dune stability and increased vulnerability to erosion. Although 137 species of vascular plants are found on the dune systems (Beach, 1988), few species are able to colonize the

dunes and initially stabilize the sands (Parks Canada, 1997a). Heightened wave action associated with storms tends to dramatically extend the zone of wave activity and increase the potential for erosion in the park (Beach, 1988). While wave effects will vary with frequency, height and angle of approach, the implications of increasingly intense storms and associated wave action on the landward beaches and tidal flats immediately offshore are potentially significant.

The barrier dune systems, salt marshes and lagoons of Kouchibouguac National Park provide critical habitat for a range of migratory shorebirds. Both the common tern and the endangered piping plover utilize critical nesting habitat in the barrier island dune systems (Beach, 1988). While the dune systems are dynamic, and both of these species adapt to changes in form and structure associated with depositional and erosional forces, possible intensification of dune destabilization may be beyond their adaptive capacity. Sea-level rise associated with climate change will inundate nesting beaches, especially where they are backed by higher ground (Herman and Scott, 1994). Warmer, drier spring weather could encourage more early visitors to plover breeding beaches, which may increase stress and nest destruction. There is limited nesting habitat outside of protected areas for either of these species and climate change could further impair breeding success. Specifically, a change in beach structure implies an alteration in available plover habitat, and the need to further modify or restrict visitor access to the beaches. This has the potential to create a conflict between different park objectives and mandates.

There are currently several fish species with declining numbers within Kouchibouguac National Park, including striped bass, smelt and gaspereau (alewife) (Beach, 1988; Delaney *et al.*, 1992; Tremblay and Beach, 1994). Monitoring results (Delaney *et al.*, 1992) indicate extreme fluctuations in gaspereau populations in the Black River, with up to 80% of potential spawning fish potentially being caught. Likewise, striped bass populations have declined over the last several years and the viability of this species is questionable (Tremblay and Beach, 1994). Potential impacts on fisheries associated with climate change and variability, such as shifts in migration patterns, changes in range boundaries at northern and southern ends, and changes in the temperature structure or salinity of water (Drinkwater, 1997), may impact already vulnerable species and limit their resilience to further disturbance. Corresponding effects on trophic systems may also result, as organisms that depend on aquatic species must adapt to changes in prey distribution or availability.

Salinity in park estuaries varies with depth, tide, freshwater discharge and distance from open water (Beach, 1988). Climate change and associated impacts (e.g., increased saltwater inundation, a possible reduction or increase in freshwater run-off, etc.) may alter the delicate relationship between salinity and a range of park organisms and ecosystems. A 0.8m rise in sea-level could cause a retreat of the freshwater table just inland, with consequent effects on the raised bogs behind the barrier islands. Plant species distributions and successional patterns may change as a result. For example, striped bass require a narrow combination of water temperature, salinity and turbulence, while

extensive eel grass beds in the park's estuary-lagoon system require water salinity levels above 5 to 7 % (Beach, 1988). Decreased salinity may inhibit growth and reproduction of eelgrass, while increased salinity may permit its expansion into riverine systems in the park. Few species directly consume eelgrass, but it does play a major modifying and productive role in lagoon-estuary ecosystems (Beach, 1988). In general, an increase in salt-tolerant species could alter vegetation patterns in the park's coastal ecosystems and lead to a net loss of species diversity (Latham in Anderson *et al.*, 1998).

Finally, while potential impacts associated with climate change and variability may not directly affect park visitor use, indirect impacts are possible. Water level (storm surge) and associated erosional changes could impact visitor use of beach areas and park infrastructure (e.g., boardwalk areas across dunes, recreational areas, and car parks in low spots behind the dunes, etc.). Issues associated with dune stabilization may require more restrictive zoning in barrier island dune systems. Already, there is a conflict between recreational use and vegetation protection requirements in sensitive dune ecosystems (Beach, 1988; Tremblay and Beach, 1994). Further destabilization of the dune systems in the park associated with sea-level rise, increasing storm severity and wave action could exacerbate this conflict.

3.1.7 Mingan Archipelago National Park Reserve

Mingan Archipelago National Park Reserve	
DATE ESTABLISHED	1984 (pending resolution of aboriginal land claim)
LOCATION	Québec – Park Geocentroid: 50.26°N, 62.67°W
SIZE	151 km^2
FEATURES	• St. Lawrence Lowlands Natural Region • Coastal chain of 900 islands and islets stretching 175 km • Unique island landscape of oddly shaped rock pillars and limestone cliffs • Mix of spruce-fir forest, fresh and salt water marshes, and rare tundra-like vegetation on moorlands and cliffs • Identified climate change as an important ecological stressor in 1997 State of the Parks Report

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	+2.0 to +27.0
SUMMER	+2.0 to +3.0	SUMMER	-17.0 to +3.0
FALL	+2.0 to +3.0	FALL	+2.0 to +13.0
WINTER	+2.0 to +7.0	WINTER	-1.0 to +24.0

Three climate change associated impacts are likely to influence the ecological dynamics and composition of the Mingan Archipelago National Park Reserve: sea-level rise and increased storm severity, changes in temperature and precipitation patterns (i.e., increased winter precipitation and decreased summer precipitation), and changes in the ocean currents around the archipelago.

A relative sea-level rise of 0.5 m by 2100 and increased storm severity have been projected throughout the Atlantic coast region. This combination will likely produce direct impacts in coastal zones, including changes in the sea ice regime, increased erosion and sedimentation, changes to water tables, increased flood risks in low lying areas, and altered salinity in nearshore and intertidal zones. The coastline in the area was rated as moderately sensitive to impacts from sea-level rise, with the most sensitive areas being the delta complexes, eroding coastal bluffs and prograded beach-ridge complexes (Shaw *et al.*, 1998a).

Coastal changes have the potential to negatively influence unique and fragile vegetation associated with nearshore cliffs and moorland (Pelletier, 1991a). For example, the botanically unique Mingan thistle, of which only an estimated 200 remain, establishes itself in a limited coastal zone characterized by a high exposure and variable moisture conditions (Pelletier, 1991a,b). An additional 53 arctic and alpine plant species grow on the archipelago's coastal cliffs and moorland habitats (Pelletier, 1991a). Most arctic-alpine species benefit from pioneer successional conditions (especially relicts in the south of their range) and increased cliff erosion could therefore prove beneficial. These species may however, experience physiological stress as a result of the warmer and drier conditions during summer months.

The biologically diverse salt marshes found on the archipelago may face increased saltwater inundation and seasonal changes in freshwater run-off. These changes will impact salinity and the distribution of organisms. In general, an increase in salt-tolerant species could lead to a net loss of diversity (see Latham in Anderson *et al.*, 1998). The coastal environments also provide important habitat for a range of migratory and nesting seabirds, such as the Atlantic puffin and the common eider. The manner in which sea-level rise and storm intensity will influence such species is unclear; however, their nesting patterns are easily disrupted (Simard, 1991; Paradis, 1991; Lachance, 1998).

Waters that flow past the Mingan Archipelago form part of the cold water Labrador Current. This current and associated upwelling of nutrient rich waters play an important role in providing fertile feeding grounds for numerous marine fauna, including nine cetacean species (e.g., blue, humpback and minke whales), and the gray seal and harbour seal (Pelletier, 1991c). This current may further cool as the Greenland ice cap melts (see Anderson *et al.*, 1998). The effect on marine diversity around the Mingan Archipelago is not clear; however, any changes will affect food chains for marine birds and mammals.

Warmer land temperatures adjacent to cooler Labrador Current waters will probably result in increased fog during the summer. Projected temperature and precipitation increases in the archipelago also have the potential to influence vegetation communities in the park. For example, Ile Nue provides a rare and vulnerable assemblage of arctic plant species uncommon elsewhere in the park and isolated from normal habitat ranges. This vegetation assemblage at Ile Nue is influenced by cold waters, wind and sea spray, snow and a short growing season (Pelletier, 1991a; Lachance, 1998), all of which are subject to alteration

under climate change. The temperature and precipitation increases projected for Mingan Archipelago National Park Reserve may negatively influence the growth and propagation of these arctic species. In addition, the influence of increased run-off, especially during the spring season, may exacerbate erosion processes. This is a particular concern in fragile or vulnerable terrestrial environments (e.g., moorlands and cliffs), and in marshes and ponds where changes to water chemistry, salinity and turbidity may result.

Potential impacts associated with climate change may not directly affect park visitor use; however many indirect impacts could occur. For example, changes in relative sea-level and associated erosional processes could influence visitor use of beach areas, and create a potential threat to park infrastructure (e.g., trails, docks, boardwalks, low-lying recreational areas). The length of season for summer recreation pursuits such as hiking, scuba diving, kayaking, and camping would be increased with warmer temperatures. Extra fog may limit boating opportunities and commercial whale watching operations (see section 3.1.2 – Forillon National Park).

3.1.8 Prince Edward Island National Park

Prince Edward Island National Park	
DATE ESTABLISHED	1937
LOCATION	Prince Edward Island – Park Geocentroid: 46.45°N, 63.18°W
SIZE	151 km^2
FEATURES	• Maritime Plain Natural Region • Narrow coastal area • Varied and dynamic landscape of shifting sand dunes and beaches, red sandstone cliffs • Marshes and ponds provide habitat for a range of seabirds

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+3.0 to +4.0	SPRING	+2.0 to +21.0
SUMMER	+2.0 to +4.0	SUMMER	-29.0 to +12.0
FALL	+2.0 to +3.0	FALL	-7.0 to +12.0
WINTER	+2.0 to +5.0	WINTER	+9.0 to +15.0

Prince Edward Island and Kouchibouguac National Parks (KNP) share similar geomorphological and ecological characteristics. The potential impacts from climate change are therefore likely to be similar to those described for Kouchibouguac National Park. As with KNP, the coasts of Prince Edward Island National Park are highly sensitive to impact from sea-level rise (Shaw *et al.*, 1998a) and increased storm severity (Goldenberg *et al.*, 1997). The combination will accelerate coastal flooding and erosion, alter sediment distribution, change the water table, and alter water chemistry in the inter-tidal and nearshore environment (Forbes *et al.*, 1997; Canavan, 1997).

The sensitive barrier islands, beaches and dune systems, salt marshes and lagoon ecosystems of the park, are likely to experience negative impacts. For example, the sparsely vegetated barrier island dune systems and associated marshes and ponds in Prince Edward Island National Park may become increasingly vulnerable to severe storms and associated wave action. Increased inundation may lead to a loss of dune stability and increased vulnerability to erosion. Increased shoreline retreat through overwashing, beach and cliff retreat, and submergence of backbarrier marshes and intertidal flats can be expected (Shaw *et al.*, 1998a). An example of the relation between the dynamic coastline and sea-level can be seen near Rustico, where the coastal road along the barrier was severed due to rapid widening of a tidal inlet.

The dune systems of the park are dynamic and characterized by constant changes in form and structure associated with depositional and erosional forces (Parks Canada, 1977). Depending on frequency, height and angle of approach, wave action associated with more intense storms will likely extend the zone of wave activity and increase the potential for erosion in the park. Erosional processes have been estimated to reduce the headlands and cliffs along much of the north coast of Prince Edward Island National Park by approximately one metre per year (Parks Canada, 1977). Dune destabilization associated with climate change may intensify erosional losses in this area of the park. If marram grass, which has an important initial role in stabilizing dune sands, is unable to cope with the more extreme conditions, the dune ecosystem may be drastically altered.

Herman and Scott (1994) suggested sea-level rise associated with climate change would inundate nesting beaches, especially where they are backed by higher ground. This is of particular concern because the dune systems, marshes and ponds of Prince Edward Island National Park provide critical habitat for a range of migratory shorebirds, including the endangered piping plover (Corbett, 1997; Parks Canada, 1997). Human use of the dunes already exerts considerable pressure on the breeding success of species that rest in these areas (Tremblay and Beach, 1994; Corbett, 1997). Because there is limited nesting habitat for these species outside of the National Parks in the region, additional climate change impacts could further impair breeding success. An earlier onset of the tourist season, associated with spring warming, could impact beach-nesting birds.

Salinity in park estuaries varies with depth, tide, freshwater discharge and distance from open water (Beach, 1988). Climate change and variability may alter the delicate relationship between salinity and a range of park organisms and ecosystems, by increasing saltwater intrusion and reducing freshwater run-off during the summer months. In general, an increase in salt-tolerant species could alter vegetation patterns in the park's coastal ecosystems and lead to a net loss of species diversity (Latham in Anderson *et al.*, 1998).

Temperature structure and salinity changes associated with climate change have important implications for fishery migration patterns, range boundaries and species composition (Drinkwater, 1997). Changes in the fishery would have important consequences for food webs, as organisms that depend on aquatic species must adapt to changes in prey distribution or availability. This may be a particular problem for certain seabird populations.

Climate change and variability may affect park use by increasing the length of the tourist season. This could be detrimental to the park, as visitor impacts to the fragile dune environment was the reason the Canada Nature Federation rated this national park as the most threatened. Sea-level rise, storm surges, and alterations to the erosion / sedimentation balance could influence visitor use of certain beach areas and threaten park infrastructure (e.g., boardwalk areas across dunes, and low recreational areas behind dunes). Increased expenditures on tourist infrastructure may be required due to the increased maintenance of boardwalks, steps, groynes and seawalls expected with rising sea-level. The current park management challenge of providing for recreational opportunities, while ensuring vegetation protection in sensitive dune ecosystems may be exacerbated by climate change impacts. More restrictive zoning may be required to ensure dune stabilization and protection of associated ecosystems.

3.1.9 Terra Nova National Park

Terra Nova National Park			
DATE ESTABLISHED	1957		
LOCATION	Newfoundland – Park Geocentroid: 48.49°N, 54.05°W		
SIZE	400 km2		
FEATURES	• Eastern Newfoundland Atlantic Natural Region • Boreal forest: black spruce, balsam fir, birch and poplar • Nesting site for bald eagles and ospreys • Archaeological evidence of aboriginal peoples		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	+2.0 to +20.0
SUMMER	+2.0 to +4.0	SUMMER	-11.0 to +7.0
FALL	+2.0 to +4.0	FALL	+6.0 to +18.0
WINTER	+2.0 to +5.0	WINTER	+7.0 to +16.0

Terra Nova National Park (TNNP), located in the Eastern Newfoundland Atlantic natural region, is characterized by massive sea cliffs on the coast that reach 200 - 300m in height (Parks Canada, 1997a). The park is 80% forested with black spruce, balsam fir, white birch, trembling aspen, red maple, lesser larch and white pine (Power, 1996). Of all the National Parks in Canada, Terra Nova is projected to experience the least temperature increase under doubled-CO_2 conditions (see section 2.3).

In comparison to other Atlantic Regional National Parks, projected sea-level rise of 0.5m by 2100 will have less of an impact on the ecological integrity of TNNP. Shaw et al. (1998a) rated the overall sensitivity of the TNNP shoreline to impacts from sea-level rise is low. Future climate change would probably increase erosion of sea cliffs if only because higher temperatures during the winter will shorten the period of sea ice cover and thus increase the energy of waves (Forbes *et al.*, 1997). This increased instability will affect seabird habitat and increase sediment supply (Forbes et al., 1995).

The large number of bogs in TNNP will most likely be affected by changes in temperature and precipitation. Various species of plants including sphagnum moss, pitcher plants, Labrador tea, leatherleaf, bog laurel and sundew thrive in these areas. Bogs provide acidic conditions conducive to these plants. It is unknown exactly how climate change will impact these areas. If the precipitation increase is sufficient, the acidity of bogs could be altered as additional minerals are leached from bog surfaces.

There remains significant uncertainty as to the effect of climate change on forest stands in both the region and in TNNP. Cox (1997) predicted increased biological productivity for boreal stands due to a shortened winter cycle. This productivity may be offset by other changes in the environment. For example, depletion of the ozone layer could cause additional long term UV-B damage, including changes in leaf structure that affect metabolism. This could lead to changes in species distribution and populations over time (Cox, 1997). Forbes *et al.* (1997) and Lenihan and Neilson (1995) suggested climate change would eventually result in a shift from boreal forest to a more temperate one. The time frame for this transition is uncertain.

Changes in the Fire Weather Index in the region may also reduce potential productivity gains in boreal stands (Cox, 1997). Likewise, temperature increases in Newfoundland would cause increased insect (as spruce budworm, hemlock looper and balsam woolly adelgid) and disease outbreaks (Power, 1996). In contrast, food chain components relying on such insects, including insectivorous birds may benefit markedly.

Shorebirds in TNNP are likely to be affected by the changes in climate. Some researchers project the coastal Labrador Current to become cooler as a result of accelerated melting of Greenland ice caps, while the warmer Gulf Stream could move more northward further offshore. Temperature changes in the sea may cause a shift in the composition of fish species off the Terra Nova coast. Seabirds will also react to these shifts. Eventually, seabird populations will redistribute to reflect the changes in temperatures in the sea (Clair *et al.*, 1997). Changes in the climate will also affect the annual cycle (moulting, breeding and migration) of birds. These events are usually triggered by day length. Changes in climate could cause a mismatch in terms of day length and changes in food supply and habitat availability (Clair *et al.*, 1997). The impact on breeding success remains uncertain.

Visitor use of the park is likely to be impacted by climate change to some extent. The period for summer activities, such as camping and hiking, will increase slightly. Projected increases in forest fire frequency may require park managers to review open fire policies and fire suppression plans. Summer conditions may be foggier with increased land temperatures and a colder Labrador Current. This would affect the mobility of whale watching and other boating activities in addition to potentially reducing visitation to the coastal sections of the park. Winter activities that occur in TNNP, such as cross-country skiing and ice-fishing are likely to be reduced slightly as a result of warmer temperatures.

3.2 Great Lakes – St. Lawrence Basin Parks

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National Parks in the Great Lakes – St. Lawrence Region are projected to experience greater climatic change than in the Atlantic region. Changing water conditions (in particular mean water levels and water temperatures) in the Great Lakes – St. Lawrence system are likely to be one of the most important climate change related impacts in the region. When GCM-based climate change scenarios are linked with hydrologic models, annual runoff and mean annual water levels are projected to decrease. It is believed that future water levels will decline to or below historical low water levels as a result of accelerated evaporation and evapotranspiration in the region (Lavender *et al.*, 1998). Lake level projections derived from the four doubled-CO_2 GCM experiments used in this study are included in Table 4. Projected water level declines will have implications for shoreline habitats and wetlands of the national parks in this region.

Table 4 - Great Lakes – St. Lawrence River Water Level Projections

Body of Water	Change in Mean Annual Water Levels (m)			
	CCCma-II	**GFDL**	**GISS**	**CCCma – CGCMI (2050)**
Superior	-0.23	-	-0.46	-0.31
Huron - Michigan	-1.62	-2.48	-1.31	-1.01
Erie	-1.36	-1.91	-1.16	-0.83
Ontario	-1.30	-	-	-0.53
St. Lawrence River *(at Montreal)*	-1.30	-	-	-

Source: Mortsch, 1999

Surface water temperatures on all of the Great Lakes are projected to increase under doubled-CO_2 conditions (Table 5). Increased water temperatures have important implications for reduced frequency of buoyancy-driven water column turnover and reduced water quality (Mortsch, 1999). The environmental impacts of this change could be significant, as spring and fall turnovers are important for nutrient distribution and the oxygenation of lakes.

Projected precipitation changes of +/- 10% will probably not increase forest fire frequencies in the La Maurice area of Québec to the same extent as areas of Ontario and Western Canada. Likewise, the coastal and island nature of the five national parks in Ontario will reduce the potential impact of increased forest fire frequency and intensity

projected for much of northern and eastern Ontario. Although increased forest fire may not have the role that it would for inland protected areas in Ontario, when combined with increased insect disturbance it may nonetheless enhance the susceptibility to invasion by more southerly species.

Table 5 - Great Lakes Surface Water Temperature Projections

Body of Water	Change in Mean Annual Surface Water Temperatures (°C)			
	CCCma-II	GFDL	GISS	CCCma – CGCMI (2050)
Superior	+5.1	+7.4	+5.6	+2.9
Michigan	+5.6	+5.5	+4.7	+3.2
Huron	+5.0	+6.0	+4.7	+2.6
Erie	+4.9	+5.0	+4.4	+2.2
Ontario	+5.4	+5.9	+4.9	+2.9

Source: Mortsch, 1999

3.2.1 Bruce Peninsula National Park

Bruce Peninsula National Park	
Date Established	1987
Location	Ontario – Park Geocentroid: 45.16°N, 81.52°W
Size	154 km^2
Features	• St. Lawrence Lowlands Natural Region • Extensive karst formations, cliffs, beaches and wetlands • North end of Niagara escarpment • Habitat for over 300 bird species and a wide variety of other flora and fauna

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
Temperature Change (°C)		Precipitation Increase/Decrease (%)	
Spring	+1.0 to +6.0	Spring	+6.0 to +24.0
Summer	+1.0 to +5.0	Summer	-14.0 to +6.0
Fall	+2.0 to +3.0	Fall	-23.0 to +7.0
Winter	+2.0 to +7.0	Winter	-2.0 to +17.0

Despite a basin-wide increase in precipitation, the long-term average level of Lake Huron is projected to decrease by between 1.3 and 2.5m as a result of climate change (Table 4). The anticipated drop in water level will reduce erosion on beaches and lower the zone of wave action on cliffs in the park. On the westside of Bruce Peninsula, this drop will dry the marshes and fens bordering the shoreline in many areas. Dryland plants may colonize the upper fringes of the marsh complex, while the outer edge of the marshes will slowly

migrate lakeward. In addition, many species such as endemic dwarf lake iris which depend on fluctuating lake levels may be adversely affected by any possible future structural measures designed to maintain artificially higher Lake Huron water levels that are better suited to other economic interests.

Lake and stream temperatures will also rise over the next century (Table 5). Warmer temperatures will likely result in later freeze-up and earlier break-up of lake ice, altering the physical characteristics of aquatic ecosystems. For example, the protective effect which solid lake ice has on the shoreline in winter storms may be lessened. A 1oC mean change in autumn or spring air temperature can change the mean freeze-up or break-up date by four to six days (Barry and Maslanik, 1992). These physical and biological effects could impact significant park features such as Gillies Lake (an oligotrophic lake) and the reef complexes which skirt the shoreline around Cabot Point.

Warmer water may also increase productivity of aquatic plants in marsh areas but could reduce the amount of oxygen available for the many fish species. The amount of available nutrients may also become more of a limiting factor in aquatic habitats, as algae and plants take advantage of warmer growing conditions.

The distribution of fish species will be changed by relative temperature differences in surface waters. Species that are at the northern end of their range, such as the centrarchid (black bass and sunfish) and percichthyid (white bass and white perch) families, are expected to expand. Walleye and yellow perch may retreat to areas of colder water (Ebener *et al.*, 1995; Smith *et al.*, 1998). Summer stream temperatures may become too high for salmonids such as brook trout (Meisner et al., 1990). Optimum temperatures for these species may instead shift to early spring or late fall when the nearshore habitat or streams are cooler (Smith *et al.*, 1998).

Decreased summer and fall precipitation will result in a lower water table and increased drought conditions. Clair *et al.* (1998) projects that runoff in the region will decline by approximately six percent. Marsh complexes will tend to dry out more often and may be colonized by white cedar. A loss of plant diversity may result.

Drier conditions could also increase the hazard of forest fires within the park. This could be of particular concern in Dorcas Bay and Huron Shore where mixed communities of jack pine, cedar, red pine, balsam fir and white spruce could result in extremely intense fires (Moreland, 1997). Doubling atmospheric CO_2 may increase the fire weather index (FWI) by 1.5 –2 times over much of Ontario (Thompson *et al.*, 1998). Colombo et al. (1998) however, project the seasonal forest fire intensity rating across the Bruce Peninsula will remain a category 3 (out of 5) under doubled-CO_2 conditions. The projected increase in fire disturbance would shift forest age class distributions down. This change would be detrimental to mature forest species (such as fishers), while providing increased habitat for the small bear population and other species that benefit from habitat associated with more fires.

With the decrease in summer and fall precipitation, plant communities may shift to more xeric species. This may result in the reduction of some of the sensitive park flora, including the 43 species of orchids, northern holly fern and the dwarf lake iris. Other species with higher drought tolerance may thrive in these new conditions.

More southerly plant species may colonize the park as their northward extent shifts. Lenihan and Neilson (1995) project the temperate summergreen vegetation community to remain dominant or possibly shift to mixedgrass prairie vegetation, depending on the GCM scenario used. Suffling *et al.* (1995) contains a more specific discussion of these shifts.

The changing conditions will also likely result in the increase in forest pests and disease (Environment Canada, 1991). Warmer temperatures and the ageing balsam fir population will probably result in greater outbreaks of spruce budworm. Overall, there will be greater ecosystem stress, which could increase the susceptibility of the natural systems to expansion of non-native invasive species. Under altered climatic conditions, the definition of native species may need to be altered to include more southerly species.

As the plant communities of Bruce Peninsula change, the wildlife will also be affected. Some species preferring dryland environments, such as eastern bluebird, may increase their range as the grassland areas expand. Others requiring wetter conditions, such as the several species of frogs and turtles, may face reduced habitat. Some of the over 300 bird species resident to the park and migrating through the area may also be threatened by the changes in plant communities. Spring migration will shift earlier and fall migration will shift later in the season reflecting change in the length of winter conditions. These relationships should be further researched to develop management plans to protect bird species.

The dry summer and fall conditions, coupled with exposure of more sand and silt to stronger winds, could result in the expansion of the dune complex at Dorcas Bay and destabilization of the ancient dune system near Cameron Lake. The existing dune vegetation may become even more sensitive as the system develops more shifting sands.

The number of visitors to the park could rise with the warmer temperatures and lower summer rainfall. Overall, climate change will probably result in a longer peak use season and higher numbers of visitors during the summer. The winter recreational season would likely be shortened. It is possible that increased winter precipitation (provided it falls mainly as snow) may result in better conditions for activities such as snowshoeing and cross-country skiing, during the shortened season. During the summer, reduced water levels may present new hazards to boaters. A longer diving season and the need to rebuild boat docks can be expected. Political pressure for Lake Huron water level regulation is the major threat to the park as the coastal fen systems are dependent on fluctuating lake levels. Climate change will not likely have a heavy impact on park infrastructure and archaeological resources.

3.2.2 *Georgian Bay Islands National Park*

Georgian Bay Islands National Park			
DATE ESTABLISHED	1929		
LOCATION	Ontario – Park Geocentroid: 44.95°N, 79.93°W		
SIZE	26 km^2		
FEATURES	• St. Lawrence Lowlands Natural Region • 59 rocky islands • 722 vascular plant species • Transition between Great Lakes-St. Lawrence Precambrian and St. Lawrence Lowlands • Rare eastern Massasauga rattlesnake, eastern fox snake and spotted turtles • Great diversity of reptiles and amphibians		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+1.0 to +6.0	SPRING	+6.0 to +24.0
SUMMER	+1.0 to +5.0	SUMMER	-14.0 to +2.0
FALL	+2.0 to +3.0	FALL	-23.0 to +7.0
WINTER	+2.0 to +7.0	WINTER	-2.0 to +17.0

Georgian Bay Islands National Park (GBINP) on Lake Huron consists of 59 small islands and shoals on the eastern edge of Georgian Bay. The park runs about 83 km along the shores of the bay. One of the characteristic features of the park is that it lies in the transition between the Precambrian Shield and the Great Lake-St. Lawrence Lowlands. Its position within the Great Lakes forest biome also ensures a mix of southern deciduous and northern boreal species.

Average water levels in Lake Huron are projected to decrease by between 1.3 and 2.5m (Table 4), which would significantly affect aquatic ecosystems and wetlands. The type of wetland will primarily determine the degree of impact. Some wetlands will migrate outward as lake levels drop while others, inland, will be reduced or disappear (Mortsch, 1998). Fluctuating water levels are vital to the maintenance of wetland diversity. There are no projections as to the long-term impact of low lake levels on wetlands in the Lake Huron region (Wilcox, 1995). Research underway on Lake Erie and Lake St. Clair wetlands is now being expanded to Lake Huron.

Increasing water temperatures (Table 5) are expected to impact species composition in aquatic ecosystems. Many species at their northern limits in the lakes are expected to expand their ranges, including species in the centrarchid (black bass and sunfish) and percichthyid families (white bass and white perch) (Smith *et al.*, 1998). Species at their southern limit, needing to retreat to cold water areas, include walleye and yellow perch (Ebener *et al.*, 1995). The water temperature during summer may be too warm for salmonids, such as brook trout (Meisner *et al.*, 1988). Optimal temperatures for this species

will instead shift to the early spring or late fall when their nearshore habitat or stream waters are cooler (Smith *et al.*, 1998). Depending on the GCM scenario, mean annual surface temperatures on Lake Huron are projected to increase 2.6 to 6.0°C (Table 5).

Forest composition is also expected to shift in GBINP. Some believe that boundaries of the boreal forest will shift as much as 500 - 1000km northwards over several hundred years (Overpeck *et al.*, 1990). Others believe that there will be a rapid shift in those borders (Suffling, 1995). Warmer temperatures will likely result in an increase in forest pests and disease, changing disturbance regimes in forest stands (Environment Canada, 1991). The seasonal forest fire severity rating for the Georgian Bay area is projected to increase from 3 to 4 under doubled-CO_2 conditions (Colombo *et al.*, 1998). Forest stands on the mainland of the park will shift as the climate changes, however, the various species located on small islands in the park will be particularly susceptible to the change in climate and perhaps may be unable to withstand it (Smith *et al.*, 1998). Biodiversity on small islands is thus likely to be reduced. Other changes associated with global warming include the reduction of soil moisture. This may induce a greater incidence and intensity of forest wildfires on the mainland (Smith *et al.*, 1998). The dieback due to climate change will also provide a greater fuel supply for potential forest fires.

Changes in forest and vegetation cover will also affect wildlife distribution and composition. Climatic shifts in forest zones will cause a mismatch in the species composition and the actual climate being experienced in the park. Increased forest fires could favour deer habitat (Smith *et al.*, 1998). The Massasauga Rattlesnake, a species closely associated with wetlands, may decline. Osprey may find that their diet of brown bullhead and other centrarchids will move from the park region under climatic change. The population of ospreys in GBINP might shift out as a result or they may adapt to feed on the fish species that will have displaced the brown bullhead.

Recreational use in the park will also be affected by climate change. Reduced winter snow cover will reduce opportunities for winter activities such as skiing. Conversely, the length of the season for summer activities will increase. Lower lake levels could restrict navigation of vessels in the narrow channels between the islands in the area. Park managers will need to monitor the ability of vessels to navigate through the area and adapt to changes in navigable waters. Political pressure to regulate Lake Huron water levels under the projected lower water level scenarios would pose an additional threat to the park's ecosystems.

3.2.3 *La Mauricie National Park*

La Mauricie National Park	
Date Established	1977
Location	Québec – Park Geocentroid: 46.83°N, 73.00°W
Size	536 km^2
Features	• Great Lakes – St. Lawrence Precambrian Natural Region • 93% forest cover • 70 plant species considered rare or of special interest • Identified climate change as an important ecological stressor in 1997 State of the Parks Report

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
Spring	+1.0 to +4.0	Spring	+4.0 to +19.0
Summer	+2.0 to +4.0	Summer	-7.0 to +10.0
Fall	+2.0 to +3.0	Fall	-8.0 to +9.0
Winter	+2.0 to +5.0	Winter	+6.0 to +28.0

La Mauricie National Park (LMNP) is located in the Laurentian forest region on the Canadian Shield. It is typical of the central part of the Precambrian region of the Great Lakes and the St. Lawrence forest biome. LMNP contains over 150 lakes with associated wetlands, which comprise about 7% of the total surface area of LMNP. Forest covers the remaining 93% of the park.

Two main influences have shaped the topography of LMNP, glaciation and the invasion of the Champlain Sea into the park's lowest areas (~10,000 years ago). This marine invasion lasted over 2,000 years and formed the marine clay terraces found along the Saint Maurice River. These marine clays are prone to slumping and landslides, causing damage to wildlife habitat and built structures. Consequences of projected increases in winter precipitation and summer drying of these marine clays should be investigated. Increased snow accumulation in combination with increased spring temperatures and rainfall will probably increase soil erosion.

Most lakes in LMNP are acidic or neutral with pH ranges between 4.1 to 7.0. (Parks Canada, 1996). Acid rain has been identified as an important stressor to the park's complex ecosystems. In their discussion of interactions and between various air issues, Maarouf and Smith (1997) indicate climate change will have a strong positive effect on acidic depositions and alter transport trajectories and deposition patterns of acidifying gases. Unless the transport trajectory changes, climate change is likely to exacerbate acidic deposition problems in LMNP.

During the summer and fall seasons, minor precipitation increases are projected by 3 of the 4 doubled-CO_2 experiments, while temperature increases of 2 to 4°C are expected. Wetlands should not be additionally stressed unless water tables are lowered (Lavender *et*

al., 1998). The lakes and rivers of LMNP also support diverse fish species, including speckled trout, lake trout, northern pike, small-mouth bass, yellow perch and walleye. The arctic char is at the southern end of its range and is thus likely to be especially susceptible to climate change impacts. Impacts of climate warming and stream salmonids have been examined by Meisner *et al.* (1988) with projections of widespread extirpation in the region. Research is needed on the combined impact of acid rain and climate warming on these species.

Extensive aquatic habitats also provide for a wide range of animals. Nineteen species of reptiles and amphibians live in the park. One notable species is the wood turtle; rare in Canada because it does not usually survive at such high latitudes. Habitat destruction, poaching and disturbance by human beings have seriously threatened its existence. If other stresses were lessened, warming may create an environment more favourable to the wood turtle.

LMNP is at the northern edge of the hardwood forests of Quebec. Thirty tree species make up a hundred distinct plant communities, distributed according to altitude, topography and soils. Climate warming will benefit species at their northern range, while species at their southern range may be extirpated. Under a doubled-CO_2 scenario, Lenihan and Neilson (1995) project a shift from boreal evergreen forest to temperate summergreen forest in the region where La Mauricie National Park is located. Seventy plant species within LMNP are considered rare and of special interest (Parks Canada, 1996). The impact of climate change on the range of these plants would be of particular importance to the park's conservation efforts and need to be further examined.

Forest fires, diseases, insect infestations and former logging operations are all recognized as having contributed to diversifying LMNP's forests. Forest protection and fire suppression practised since the park's establishment, have contributed to the reduction in forest patchiness and the promotion of successionally older forest (Parks Canada, 1996). An altered fire regime has been identified as one of five top problems for LMNP (Parks Canada 1997a, 1998a). In contrast to Ontario and Prairie Region parks, forest fire frequencies over eastern boreal forests may decrease under doubled-CO_2 conditions (Bergeron and Flannigan, 1995). A decreased fire regime would increase forest composition change in Quebec, as the boreal forest relies on semi-regular fire occurrence. A slightly decreased forest fire frequency may enhance red and white pine, balsam fir and eastern white cedar stands.

Upland communities however, are much more likely to become stressed for prolonged periods with greater evapotranspiration. Some conifers like hemlock will be at a competitive disadvantage under conditions of water stress. Such conditions may shift the balance to favour species that are more drought-tolerant, such as beech.

LMNP supports many animal species including black bear, moose and beaver. Some species, such as beaver and bear, will benefit from the increase in early successional habitat resulting from increased forest fire frequency. With the increase in winter

temperatures, the hibernation period for bear may be shortened. However, increased winter precipitation may increase snowpack, hindering ungulate access to browse.

Many recreational activities take place within LMNP year round such as hiking, wildlife observation, mountain biking, sport fishing, cross-country skiing and camping (including winter camping). A longer, summer season created by increased temperatures may lengthen the tourist season. Greater visitation can be economically beneficial but heighten associated adverse environmental impacts. Conversely, the season for winter activities will be reduced. With the potential for a greater number of visitors in LMNP, additional precautionary measures may be needed to protect people and property from harm caused by landslides in marine clay areas.

Climate warming and its associated uncertainty may force park managers to re-evaluate wildlife management, fire and fisheries management policies in LMNP. Park management has traditionally taken a non-intervention approach to allow natural processes to occur. In the face of climate change, a more active management role may be needed.

3.2.4 Point Pelee National Park

Point Pelee National Park	
DATE ESTABLISHED	1918
LOCATION	Ontario – Park Geocentroid: 41.98°N, 82.52°W
SIZE	15 km^2
FEATURES	• St. Lawrence Lowlands Natural Region • On a sand peninsula jutting 17 kilometres south into Lake Erie • Representative Carolinian Forest species such as sycamore, sassafras and red mulberry • Large section of marsh protecting numerous species of flora and fauna • Famous for spring and fall bird migrations as well as fall Monarch butterfly migrations

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+1.0 to +8.0	SPRING	+7.0 to +27.0
SUMMER	+1.0 to +5.0	SUMMER	-10.0 to +7.0
FALL	+1.0 to +3.0	FALL	-36.0 to +27.0
WINTER	+1.0 to +7.0	WINTER	-4.0 to 12.0

The average long-term level of Lake Erie is projected to drop between 1.0 and 1.9m as a result of climate change (Table 4). This drop will have profound impacts on the ecological structure and functions within the park. The lower waterline will reduce the erosive energy along foreshore areas, such as the east beach, witnessed over the past 50 years. This could possibly counter the interruption of sediment supply caused by erosion control structures outside the park. If the lake levels decline as projected, windstorms and the

seiche effect will have less impact on the shoreline. The warmer temperatures will also result in later freeze-up and earlier break-up of lake-ice, altering the physical characteristics of aquatic ecosystems. Under a doubled-CO_2 scenario, ice cover duration was reduced 8 to 13 weeks on Lake Erie (Assel, 1991). This reduction in ice cover could also result in less shoreline protection during winter storms.

The wetland marshes of the Northeast corner of the park may partially dry out, particularly during low water period in late summer and early fall. Because of marginal sand spits, the marsh vegetation will be prevented from moving lakeward. Since the average depth of the marsh complex is about 2 metres, the projected 1 to 1.91m drop in water levels will result in many wetland areas becoming colonized by species tolerant of more mesic conditions. The species diversity of the wetlands will decline (Wall, 1998). This could further threaten rare species such as rose swamp mallow and spotted turtles. Low water levels will also change the marsh by providing conditions for cattail mats to expand into the open water ponds. Shrub and tree invasion is likely at the margins. Nesting sites for common and black terns as well as numerous other waterfowl may become more accessible to predators such as racoon and mink. While new littoral habitats may form eventually, lost nearshore habitat will be greater in the short-term (Mortsch *et al.*, 1998).

The drop in lake levels will lower the water table throughout the park. When coupled with a potential decrease in summer and fall precipitation and a projected decrease in runoff (approximately 6 percent in the region - Clair *et al.*, 1998), some upland areas may become more prone to drought. Plant communities may shift to more xeric species, particularly in the ridge and trough section of the park on old dune complexes. In this area, the ridge species may spread across the troughs as the water table drops below the rooting zone. Dune and sand plain areas may expand with the drier conditions and increase in wind erosion. This would benefit some rare species such as prickly pear cactus, eastern mole and eastern fox snake (Parks Canada, 1978). Some tree species will suffer increased drought stress with premature leaf fall (as in the 1999 dry period). A drop in lake level could strengthen the root support of trees previously susceptible to blowdown. The forested sloughs used as nesting sites by the rare prothonotary warbler may dry out.

Lake surface temperatures will also rise with warmer air masses. Overall, surface water temperatures in Lake Erie are projected to increase from 2.2 to 5.0 °C (Table 5). Warmer water may increase plant productivity in marsh areas but could reduce the amount of oxygen available for fish.

Warmer temperatures and less summer and fall precipitation could lead to increased forest fire hazard. An increase in convective cell precipitation, and consequently thunderstorm activity, could result from a warmed climate (Chiotti, 1998). More frequent and intense thunderstorms increase the hazard of lightning ignitions within the park. The seasonal

forest fire severity rating for the Point Pelee area is projected to increased from 3 to 4 under doubled-CO_2 conditions (Colombo *et al.*, 1998). Fires have historically kept sections of the forest in an early successional state; however, due to the small size of the park and proximity to infrastructure and the public, fires would have to be very closely monitored and probably extinguished.

The change in physical conditions will likely alter the species composition of plant communities within the park. Some species more representative of the northern hardwood forests may decrease while species typical of western tall grass prairie such as prairie rose, and bearberry may increase. The change in conditions could also result in the introduction of new dry land Carolinian species as they shift northward, but only provided they are able to migrate around Lake Erie and through an intensely cultivated landscape. Warmer temperatures will likely result in an increase in forest pests and disease in the forest stands of Point Pelee (Environment Canada, 1991). The changes in temperature and precipitation coupled with increased disturbance and altered nutrient regimes will result in greater ecosystem stress, potentially increasing the susceptibility of natural systems to expansion of invasive species. Point Pelee already has more exotic species than any other Canadian National Park (247 plant and animal species) (Parks Service, 1991; Parks Canada, 1998).

Changing climatic and environmental conditions may also alter the ranges of some of the 72 nesting bird species in the park. Some may move to areas further north, while new species from the south may extend their ranges to include Point Pelee. In addition to the resident wildlife populations, Point Pelee is famous for the annual bird and butterfly migration through the park. With increased temperatures, it is likely that the spring migration will shift earlier in the season while the fall migration will likely shift later. A study of migratory birds in Michigan, found 26 of 27 species have arrived earlier in the spring than 30 years ago (Carter, 1999). Altered migration patterns will change visitor use of the park as bird watchers adjust to the new cycles and new species. The impacts of climate change on the winter habitat of birds and butterflies could also have a major impact on populations of migratory species.

The number of summer visitors to the park could increase with the warmer temperatures and drop in summer rainfall. The local economic impact of a longer peak season will be positive. Unfortunately for some of these visitors, populations of insects such as flies, mosquitoes and ticks are favoured by warmer and wetter conditions, particularly in winter and spring (Shriner and Street 1998). The possibility of increased transmission of Lyme disease from ticks to park visitors should be investigated. Opportunities for canoeing may be reduced due to a lack of open water (Wall, 1998). Visitor management plans should be developed to define the level of acceptable change from human use. Climate change will not have a large impact on park infrastructure and archaeological resources. There may be more wind damage to infrastructure and more blown sand in parking lots, but flood damage should lessen.

3.2.5 *Pukaskwa National Park*

Pukaskwa National Park			
DATE ESTABLISHED	1971 (amended 1978)		
LOCATION	Ontario – Park Geocentroid: 48.29°N, 85.94°W		
SIZE	1,878 km^2		
FEATURES	• Central Boreal Uplands Natural Region • Arctic alpine flora • Acid sensitive lakes • Boreal forest / Jack pine forest • Interactions between moose, wolf and woodland caribou		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+1.0 to +4.0	SPRING	+2.0 to +27.0
SUMMER	+1.0 to +4.0	SUMMER	-3.0 to +5.0
FALL	+2.0 to +3.0	FALL	-9.0 to +1.0
WINTER	+2.0 to +7.0	WINTER	+5.0 to +25.0

Pukaskwa National Park (PNP), located along the shores of Lake Superior, is greatly influenced by the rate and magnitude of water level fluctuations. Lake Superior has been observed to fluctuate within a range of up to 2m over the past 100 years (Sanderson, 1989). Climate change is projected to decrease average water levels in Lake Superior from approximately 0.2 to 0.5 metres (Table 4). Total annual runoff is projected to decline by approximately 2% in the region, with peak flows remaining in May (Clair *et al.*, 1998). Finally, under a doubled-CO_2 scenario, ice cover duration was reduced 5 to 13 weeks on Lake Superior (Assel, 1991).

Arctic-alpine plant species along the shoreline are likely to be negatively impacted by lake level changes. Small populations of Arctic-alpine plants have been found in sheltered areas. Some plants are as much as 1000km south of their normal range. Their presence is due to a combination of physical factors, such as: the moderating effects of Lake Superior on summer temperatures, wave and ice action eroding bedrock and limiting the establishment of forest species, the cooling and evaporation effects of the prominent westerly winds, coastal fog, and the low accumulation of snow cover in the winter (Skibicki, 1995). With the expected lowering of Lake Superior water levels, increased temperatures and winter precipitation, the survival these Arctic-alpine populations is a concern.

Acid rain is problematic in the PNP region. The Precambrian bedrock and glacial till found in PNP has little potential to buffer acidity. A study of 59 lakes within PNP found 32 to be extremely sensitive to acidification (McCrea *et al.*, 1992). Increased precipitation may place additional stress on PNP's already acid-sensitive lakes. As local soil and lakes become increasingly acidified, terrestrial and aquatic habitat becomes more degraded.

Species abundance and composition could easily be affected by increased acid precipitation, possibly resulting in range expansions and contractions of sensitive species such as white pine, red maple, and sugar maple. Due to sensitivity to acidification and increased precipitation, many important sport fish could also be affected. The common shiner, fathead minnow and slimy sculpin have minimum pH survival thresholds of 5.9, while lake trout will cease reproduction at 5.6 (McCrea *et al.*, 1992).

Plant communities will also likely shift northward in response to changing temperature conditions. According to Rowe (1989), shifts in ecozones in the interior of Canada could be as much as 450km if temperatures warmed 3°C. Overpeck *et al.* (1990) have made similar predictions. Black spruce, jack pine, white birch and trembling aspen dominate vegetation in the Pukaskwa area. Trees with light, mobile seeds, such as birch and poplar, will be able to shift northward more quickly in response to changing climatic conditions. Boreal species, such as white spruce, only migrate 3 to 4km over a 40 year period (Rowe, 1989); not fast enough to adapt to changing conditions. Species with heavy seeds will likely face local extinction without active intervention (i.e., translocation). Understorey and exotic species are expected to be able to respond to climatic changes faster than tree species leading to forest community destabilization and increased tree mortality (de Groot and Ketner, 1994).

Forest disease, insects and fungal outbreaks may increase with warmer temperatures. In particular, spruce budworm is favoured by warm summers. Wildfire frequencies will likely increase in areas with a high proportion of defoliated or dead trees caused by increased pathogen attacks. Doubled-CO_2 may increase the fire weather index (FWI) by 1.5 – 2 times over much of Ontario (Thompson *et al.*, 1998). The seasonal forest fire severity rating for the PNP area is projected to increased from 2 to 3 under doubled-CO_2 conditions (Colombo *et al.*, 1998). Other studies also indicate an increase in the frequency and severity of fires in boreal forests (Stocks *et al.*, 1998; and Suffling and Speller, 1998), but PNP will be affected to a lesser extent (Suffling, 1995).

Although adaptation to fire regime and distribution patchiness will help boreal sub-zones adjust relatively rapidly to climatic change, if fire frequencies and magnitudes become too extreme, adaptation may not be possible. Research into the magnitude of fire frequency changes should be conducted. Methven and Feunekes (1992) found small scale fires promote age class diversity but as fire frequency increased the reverse effect occurred (hardwoods dominated the forest and age class diversity decreased). Maximum diversity occurred with an intermediate fire cycle of 115 years. This finding is in accordance with other studies (e.g., Suffling and Speller, 1998). Diversity is desirable as it supports rapid response to fire regime changes prompted by climate change. The transition to young regenerating forests is of particular concern for wildlife species requiring use of mature forests such as fisher and red squirrel.

In addition to potentially losing mature forests, wildlife will also need to adapt as their habitat migrates during changing climate conditions. Thompson *et al.* (1998) suggested

moose and caribou populations will decline significantly in response to habitat changes. This is of particular importance to PNP due to its program to protect the woodland caribou. In contrast, white-taiied deer whose population is low in PNP will likely increase. With more deer, the population of deer ticks and the potential for Lyme disease could increase, potentially posing an increased threat to park visitors.

There are many potential cultural impacts induced by climate change. Changes in the species and abundance of fish in lakes and streams in Pukaskwa may change sport fishing in the park. In addition, projected lower lake levels will create problems for boating facilities, trails, and natural features of interest to tourists along the shoreline. The summer recreation season will likely increase in length; however, the season for winter activities will be shortened (Wall, 1988). Finally, the increase in the risk of forest fires may require modified plans to protect park visitors when conditions are hazardous.

3.2.6 St. Lawrence Islands National Park

St. Lawrence Islands National Park			
DATE ESTABLISHED	1914		
LOCATION	Ontario – Park Geocentroid: 44.34°N, 76.07°W		
SIZE	9 km^2		
FEATURES	• Great Lakes – St. Lawrence Precambrian Natural Region • Extensive wetlands • 41 rare plants and 4 rare reptiles • Identified climate change as an important ecological stressor in 1997 State of the Parks Report		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+1.0 to +5.0	SPRING	+3.0 to +20.0
SUMMER	+1.0 to +5.0	SUMMER	-18.0 to +5.0
FALL	+2.0 to +3.0	FALL	-11.0 to +5.0
WINTER	+2.0 to +5.0	WINTER	+8.0 to +15.0

The St. Lawrence Islands National Park (SLINP) is made up of 16 islands and parts of 5 other islands in the St. Lawrence River, as well as a mainland base at Mallorytown Landing. Access to SLINP is mainly by boat. The St. Lawrence River and an extensive system of wetlands constitute SLINP's aquatic ecosystem. Despite the island context of SLINP, limited detailed information is available on these aquatic ecosystems. With long-term average water levels in the St. Lawrence projected to decline by perhaps 1.3m (Table 4), water level regulation directives at Lake Ontario will need to be reviewed in detail to understand the potential impact on the park. The International Joint Commission has recently initiated a review of the current regulation plan for Lake Ontario that will consider climate change.

GCMs used in this study indicate temperature increases throughout the year. Decreases in precipitation are foreseen for summer and fall seasons with increases in spring and winter. Changes in winter ice conditions are anticipated in response to the warmer temperatures. Barry and Maslanik (1992) found that a 1°C change in autumn or spring air temperature could change the mean freeze-up or break-up date by four to six days. More snowfall and higher spring temperatures will likely lead to rapid spring melting (freshet still in April), with total annual runoff expected to decline by approximately 6% in the region (Clair *et al.*, 1998). Due to granitic bedrock and thin soils, little of the spring melt would be able to infiltrate into the ground, leading to increased soil erosion. With decreased precipitation, higher evapotranspiration, and lower soil moisture in the summer, wetland systems are likely to dry more. Lower St. Lawrence River levels will likely have implications for shoreline habitats and wetlands. However, river levels may be artificially stabilized with existing or additional control structures. Water level regulation would mean inland and river wetlands would respond differently to projected climatic changes.

Acid rain is increasing in the Thousand Islands region and is one of the main stressors in SLINP (Parks Canada, 1997). With anticipated increases in winter and spring precipitation, research is needed to examine the impacts of an increase in acid precipitation on vegetation and wildlife within the park. Additional acidic precipitation would exacerbate current stress on plants and wildlife.

The Thousand Islands are remnants of an ancient mountain chain, the Frontenac Axis. Granitic outcrops and complex ancient rock formations provide the park with a rich variety of microhabitats. In addition, many plants and animals in the area are favoured by the climate moderating effects of the St. Lawrence River. The Islands form a land bridge from south-east to north-west across the St. Lawrence River, facilitating the movement of wildlife through the area (Parks Canada, 1997). Large mammals can migrate relatively easily either by swimming or by crossing the ice, and thus can adapt to changes in climate much easier than smaller mammals. Barriers restricting the movement of species may threaten their very existence, therefore disruptions to this area may produce an effect out of proportion to its size (Parks Canada, 1998). An increased ice-free season on the St. Lawrence River may reduce winter mammal movement.

The region is a transition zone for flora and fauna. Broad-leaf deciduous species dominate the park's forests, but intermingle with those of the boreal forests and to a lesser extent those from the Atlantic coast.

A total of 41 rare plants and 4 rare reptiles inhabit the park. These include pitch pine, the black rat snake, and deerberry. Reptiles may benefit from increased temperatures while amphibians may suffer from drier summer conditions. Possible soil erosion and wetland disruption due to climate change will negatively affect many species.

With climate change, increased forest fires are likely. Doubled-CO_2 may increase the fire weather index (FWI) by 1.5 to 2 times over much of Ontario (Thompson *et al.*, 1998). At

the eastern end of Lake Ontario, the seasonal forest fire severity rating is projected to increase and persist for a greater length of time under doubled-CO_2 conditions (Colombo *et al.*, 1998). Due to high visitor use in a small area, the fire management strategy has been to suppress wildfires in SLINP. The park's island composition provides a relatively safe environment to employ controlled fire techniques. A detailed fire management policy will be needed to guide managers in making management decisions.

Forest insects and disease have been a major force shaping forest succession in the region. Infestations are generally short and limited in area, with many trees hardy enough to withstand this period of stress (Parks Canada, 1998). Additional climate stress may weaken some trees, resulting in the inability to withstand insect and disease attacks. The net result is unclear.

Water recreation is very popular in SLINP. Changes in water levels would have important implications for the tourism industry. Docks and other boating structures essential for park access are sensitive to water level changes. The impact on the 109 archaeological sites already suffering from erosion problems (Parks Canada 1997, 1998) is uncertain. Potentially increased precipitation may exacerbate erosion problems at some sites, while lower water levels on the St. Lawrence River may lessen erosion at others.

3.3 Prairie Parks

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With the exception of the Arctic Region, national parks in the Prairie provinces are projected to experience the greatest temperature increase under doubled–CO_2 conditions. The implications of projected precipitation changes for seasonal hydrology are also important in the Prairies. Increased drought will adversely affect important wetland areas and increase the frequency and intensity of forest fires in the northern sectors of the region.

Several Prairie region parks are located along ecotones and the magnitude of projected climate change in the region suggests these parks are likely to be more susceptible to ecological shifts than parks in most other regions. Analysis of Lenihan and Neilson's (1995) study, indicates that all national parks in the Prairie region would undergo a shift to another forest formation type (Table 6).

Table 6 – Projected Changes in Forest Vegetation Formations

National Park	Current Forest Formation	Projected Forest Formation (GISS Scenario)	Projected Forest Formation (GFDL Scenario)
Elk Island	Boreal Summergreen	Mixed Grass Prairie	Short Grass Prairie
Grasslands	Mixed Grass Prairie	Short Grass Prairie	Short Grass Prairie
Prince Albert	Boreal Evergreen	Boreal Summergreen / Temperate Evergreen	Short Grass Prairie
Riding Mountain	Boreal Evergreen	Boreal Summergreen / Temperate Summergreen	Boreal Summergreen / Mixed Grass Prairie
Wood Buffalo	Boreal Evergreen	Boreal Evergreen / Summergreen	Short Grass / Mixed Grass Prairie

Data Source: Lenihan and Neilson, 1995.

3.3.1 *Elk Island National Park*

Elk Island National Park	
DATE ESTABLISHED	1913
LOCATION	Alberta – Park Geocentroid: 53.59°N, 112.88°W
SIZE	194 km^2
FEATURES	• Southern Boreal Plains and Plateaux • Remnant of the Aspen parkland • Protection of elk • Moose, bear, beaver and coyote also inhabit the hills and stands of aspen

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +5.0	SPRING	+2.0 to +29.0
SUMMER	+1.0 to +3.0	SUMMER	-11.0 to +17.0
FALL	+2.0 to +4.0	FALL	-10.0 to +36.0
WINTER	+2.0 to +5.0	WINTER	+4.0 to +29.0

Elk Island National Park (EINP) is a characteristic remnant of the southern boreal plains and plateau region where the aspen parkland has been preserved. The park region is generally flat to gently rolling, but EINP is located in a hummocky area with clay soils and poor drainage. Management of EINP, originally set up to protect a herd of elk, was guided by three priorities: healthy large ungulates, fire prevention and public access (Blyth and Hudson, 1992). In face of climate change however, re-evaluation of management policies may be needed.

The aspen parkland is a transition zone between the northern boreal forest and the southern grasslands, and is a landscape maintained by fire and grazing. The remnant aspen parkland in EINP provides critical habitat for large populations of native herbivores such as bison, elk, moose and deer. In the past, EINP has supported many combinations of burning and grazing intensities. The park may be able to adapt to the increased fire frequency projected under climate warming. For example, a doubling of CO_2 may increase the fire weather index ratio by a factor of 1.0 in the region (Thompson et al., 1998).

According to Herman and Scott (1992), under doubled-CO_2 scenarios, boreal species and their habitats would eventually disappear to be replaced by more southern species. Projected warming would likely lead to a gradual change in species composition favouring grasslands instead of forest ecosystems (de Groot and Ketner, 1994). Lenihan and Neilson (1995) project a shift from boreal summergreen plant community to either shortgrass or mixedgrass prairie, depending on the GCM scenario used. Understorey species are likely to respond faster to warming than trees, leading to a destabilization of the entire ecosystem (de Groot and Ketner, 1994).

With temperature increases favouring intrusion of grassland into previously forested areas, a biome shift will likely occur within EINP. Animal species favoured by grassland, such as elk, western meadowlark and badger, will be more likely to adapt to changing conditions. Other factors also associated with climate change complicate this assessment (e.g., flooding, increased winter exposure to predation, and desiccation). Small non-hibernating mammals are likely to experience greater disturbance due to increased winter exposure than to summer desiccation risks. Conversely, reptiles and amphibians will be relatively unaffected by winter factors due to deep hibernation, and may benefit from increased summer temperatures.

Maintaining large ungulates is a major management goal in EINP, and the issue of carrying capacity emerged as early as 1928. At the time, EINP's ungulate populations were determined to be below the proposed carrying capacity of 1400 – 1500 bison. Small annual population reductions were however conducted as a preventative measure (Blyth and Hudson, 1992). In 1935, when insufficient numbers of ungulate were removed, winter populations of bison and elk exceeded 2000 resulting in significant winter mortality. This incident has shown that success of protection would require population numbers to be kept below the established carrying capacity levels. Additional ungulate mortality due to climate changes may be acceptable and simply replace other management techniques.

Greater fire frequency with climate warming may increase forage production, palatability, and nutritional value to ungulates. Thus, populations may tend to increase. Ungulate management policies will need periodic review to adjust to these and other changes. Forest fires can be beneficial from an ecosystem perspective, as they regenerate forest diversity. Fires also destroy mature forests, which would be detrimental to species requiring mature forest habitat. Increased fire activity can contribute to greater forest habitat fragmentation, favouring more continuous grasslands in the landscape.

Clair *et al.* (1998) project increased annual runoff of approximately 16% in the EINP region, with peak flows occurring a month earlier. Lake and stream temperatures can be expected to increase under warmer conditions. Some fish species currently found in the park might not be able to tolerate warmer temperatures. Shuter *et al.* (1998) found that higher temperatures and low water levels could cause many species in inland lakes and streams to shift northward by approximately 150 km for every 1°C rise in average temperature.

EINP park managers must be able to determine more accurately the potential impacts of climate change on recreation management plans. Summer activities may be extended at the expense of cross-country skiing and snowshoeing seasons. In addition, some fish species may be unable to tolerate warmer water temperatures, changing sport fishing in the park. Finally, the significant number of archaeological sites found within EINP warrant research regarding preservation under climate change conditions.

3.3.2 *Grasslands National Park*

Grasslands National Park	
DATE ESTABLISHED	1975 (amended in 1981, 1988)
LOCATION	Saskatchewan – Park Geocentroid: 49.10°N, 106.89°W
SIZE	450 km^2 (906 km^2 eventually)
FEATURES	• Prairie Grasslands Natural Region • Canadian mixed-grass prairie • Colonies of blacktail prairie dogs • Badlands (wind and water erosion) • Dinosaur fossils • Remnants of aboriginal settlements • Spear, wheat, blue grama grass and rare prairie flora • Identified climate change as an important ecological stressor in 1997 State of the Parks Report

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+1.0 to +8.0	SPRING	+1.0 to +41.0
SUMMER	+1.0 to +5.0	SUMMER	-34.0 to -6.0
FALL	+2.0 to +4.0	FALL	-16.0 to +2.0
WINTER	+3.0 to +8.0	WINTER	+11.0 to +26.0

In 1981, the federal government and province of Saskatchewan signed an agreement to establish the Grasslands National Park (GNP) in southern Saskatchewan. This agreement was later revised in 1988 (Gauthier and Henry, 1989). Currently, 50% of the lands (450 km^2) have been acquired for the park. Grasslands National Park is divided into East and West blocks. The primary ecosystem in the east block is natural prairie grassland complemented by naturally eroded badlands. Natural prairie also dominates the western half of the park. Climate change scenarios project increased temperatures during each season. The models also project a substantial increase in winter and spring precipitation (a range of +1 to +41%), but generally decreased precipitation in the summer and fall.

Studies on the aquatic systems in the prairie regions and in the park itself are limited. Further research will be necessary to comprehensively assess the impacts of climate change (Herrington *et al.*, 1997). Projected increases in precipitation during the winter and spring season will lead to increasing erosion and sediment transport (Herrington *et al.*, 1997). Floods during spring thaw will cause streams to widen, possibly disturbing aquatic habitat (Herrington *et al.*, 1997). Other impacts on streams and rivers will include changes in the timing and extent of runoff. This in turn will affect the rate of nutrient and sediment flow into streams and rivers (Carpenter *et al.*, 1992). With the anticipated lower precipitation and higher temperatures during the summer, base stream flows in the park will likely decrease. Some permanent streams will likely become intermittent under these conditions.

Under projected climatic changes, water temperatures in streams and rivers are expected to increase (Regier and Holmes, 1991). Temperature changes in the park will lead to less dissolved oxygen in aquatic systems. Increased UV-B radiation will also severely affect the development of aquatic invertebrates (Cash, 1997). Warm and cold water species will be affected by temperature changes with an increase range extent for the former, and a retreat to colder conditions for the latter (Carpenter *et al.*, 1992).

Drought frequency in GNP will possibly increase as a result of increasing summer temperatures, increasing evapotranspiration rates and decreased precipitation. However, the type of drought (hydrologic or agricultural) remains uncertain (Herrington *et al.*, 1997). The potential for wildfires will increase under these conditions. Bazzaz and Fajer (1992) noted that under increased carbon dioxide scenarios, various species of grass did not fare well except for *Bromus tectorum*. It is believed that a proliferation of this introduced species of grass will further increase the frequency and severity of wildfires in the region. Increasing drought frequency and intensity is likely to cause expansion of saline soil areas. Plant community composition could be altered, reflecting changes in summer temperature and precipitation regimes. Lenihan and Neilson (1995) project a shift from mixedgrass prairie to shortgrass prairie under doubled-CO_2 scenarios. With warmer and drier conditions, plants using the C_4 photosynthetic pathway (generally the 'warm season grasses' and smaller plants) should begin to have a competitive advantage over plants using the C_3 pathway (cool season grasses, etc.) (Ricklefs, 1990). However, this effect may be compensated slightly by higher atmospheric CO_2 concentrations. These higher concentrations may increase the efficiency of C_3 photosynthesis more than in the C_4 process (Ricklefs, 1990). Thus, further research is necessary to assess how much changing physical conditions and CO_2 concentrations would favour C_4 over C_3 species within the park. For instance, the phenology of C_3 and C_4 plants in relation to the seasonality of spring is critical to their success.

Grasslands National Park is home to several rare and endangered species including one of the few remaining black-tailed prairie dog colonies in Canada (Gauthier, 1993). Further research is needed to determine the impacts of climate change on these populations. Although GNP is home to the endangered burrowing owl, it is uncertain how climate change will impact this species. It is likely that insect species composition will change in GNP. One of the expected changes is the number of adult grasshoppers that will thrive in conditions where rainfall is limited; this may help the owls (Gratto-Trevor, 1997).

Climatic changes in the park will also have an impact on wetlands and waterfowl. Larson (1995) noted that parkland wetlands are more sensitive to climate change in comparison to grassland wetlands. Waterfowl that currently breed in the park may move to parkland wetlands as grasslands expand northward (Larson, 1995). Waterfowl breeding is dependent on temperatures during the month of May and precipitation during the spring season. Changes in these two variables will cause a shift in breeding patterns and species composition within the region (Gratto-Trevor, 1997). Drought may also impact waterfowl as cases of avian cholera have been recorded where higher concentrations of birds are found in fewer wetlands (Gratto-Trevor, 1997).

Changes in temperature can effect the supply of food for waterfowl. Periods of insect emergence would be influenced by the weather and thus, would act as a clear indicator of climate change (Johnson, 1993). It is likely that insect species composition will change in GNP. One of the expected changes is in the number of adult grasshoppers that will thrive in conditions where rainfall is limited (Gratto-Trevor, 1997). Mosquitoes and flies are also likely to increase under warmer conditions.

Finally, impacts on park visitor use will be significant. Winter activities such as cross-country skiing may suffer due to the shortened winter season and milder temperatures (Meyer, 1997). Visitor use in the summer may increase with more opportunities for picnicking and camping. A rise in complaints about mosquitoes and flies likely to increase, as warmer and wetter spring conditions enhance insect populations (Russell, 1993; Shriner and Street, 1998). The need for open fire bans may grow as the summer fire hazard increases. The impact on visitor experience and park use in the early part of the summer is unclear.

3.3.3 Prince Albert National Park

Prince Albert National Park	
DATE ESTABLISHED	1927
LOCATION	Saskatchewan – Park Geocentroid: 53.95°N, 106.36°W
SIZE	3,874 km^2
FEATURES	• Southern Boreal Plains and Plateaux Natural Region • Aspen Parkland, Boreal Plains and Fescue Grasslands • Woodland caribou • Uplands and lowlands (488 – 732 m) • Only fully protected colony of American white pelicans in Canada • Grey Owl's cabin and grave site

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+1.0 to +5.0	SPRING	+10.0 to +28.0
SUMMER	+1.0 to +4.0	SUMMER	-10.0 to +16.0
FALL	+2.0 to +4.0	FALL	-9.0 to +22.0
WINTER	+3.0 to +8.0	WINTER	-1.0 to +35.0

Located 65 km north of the city of Prince Albert, Prince Albert National Park (PANP) is characterized by two drainage basins divided by the Waskesiu Hills. PANP lies in the southern boreal plains and plateaux region. The park is a transition zone between the grasslands and boreal forest biomes. Grasslands are primarily found in the south-west portion of PANP while the boreal forest is found in the north. Both mixed grass and fescue grasslands can be found in the grasslands ecoregion of the park. Aspen groves and a mixedwood zone mark the transition to the boreal ecozone. PANP also features a network

of lakes and rivers, making it an ideal habitat for many wildlife species including American white pelicans (Parks Canada, 1998). The park also hosts a population of woodland caribou.

Climatic change scenarios indicate a substantial increase in temperatures throughout the year in PANP, ranging from a high of 3 to 8°C during the winter to a low of 1 to 4°C in the summer. Precipitation in the park is also projected to increase. Winter and spring precipitation is projected to remain near current levels or increase by as much as 35%. There is more uncertainty among the GCMs in terms of summer and fall precipitation.

It is anticipated that the volume of spring runoff will increase due to the precipitation deposited during winter and spring while summer flows will decrease (Herrington *et al.*, 1997). Clair *et al.* (1998) project that total annual runoff will increase by approximately 16% in the region, with peak runoff occurring in June rather than July, as is currently the case. With a greater volume of water entering the system during the spring, it is likely that increased flooding and faster rates of erosion and deposition will occur (Herrington *et al.*, 1997). Impacts on the hydrological cycle in the park have been projected but confidence in those forecasts varies (Herrington *et al.*, 1997). Further research is needed to better understand the probable impacts of increased precipitation on PANP.

Impacts on vegetation in the park will vary according to biome. Increased temperatures will cause an increase in evaporation rates, lower soil moisture levels, and more incidents of drought stress. Grasslands have a higher tolerance of temperature increase and drought conditions. Species better adapted to higher temperatures and drier conditions, such as C4 species (refer to Grasslands National Park, Section 3.4.2), may become a threat to established species (de Groot and Ketner, 1994). Grasslands in the park will probably continue to expand, displacing forest communities. These effects are also discussed under Elk Island and Grasslands National Parks (sections 3.3.1 and 3.3.2).

While the grasslands of PANP will be able to adapt to changes in climate, the boreal forests of the north will be negatively impacted. The range of these forests may shift northward and out of PANP (Wheaton, 1997). Suffling (1995) believes that this change will occur rapidly under influence of increased forest fire. Some more drought tolerant species such as aspen and jack pine will be favoured, while others such as balsam fir will decrease (Vetsch, 1986). Lenihan and Neilson (1995) project a shift from boreal evergreen communities to either temperate evergreen, boreal summergreen or shortgrass prairie, depending on the GCM used. While it is projected that there could be an eventual shift in regional biomes, the extent of the impact at the local level remains unclear (Vetsch, 1986 and Wheaton, 1997).

Intentional fire suppression during several decades has led to the lack of regeneration of fire-adapted species in PANP (Vetsch, 1986). It is believed that boreal forests will be most susceptible to fires given the, "...high degree of decadence, amount of fuel...and the highly combustible nature of coniferous cover types due to organic undergrowth..." (Vetsch,

1986:105). In addition, increased fuel accumulation resulting from increased insect and disease outbreaks could further elevate forest fire danger (Wheaton *et al.*, 1988). In order to lessen the impact of fire hazards, it is suggested that prescribed burns be conducted (Vetsch, 1986).

PANP is home to the second largest pelican breeding ground in Canada. Located on Heron Island in Lavalee Lake, the colony is the only fully protected nesting colony of American white pelicans in Canada (Vetsch, 1986). Low water levels in the lake may expose nesting sites to predators. Without protective measures, this will likely reduce the number of breeding pelicans in the park. Conversely, higher temperatures will result in earlier ice break up, opening up more suitable habitat to the north of the park for the pelicans (Wall, 1989). The northward shift of the 0°C April isotherm approximates the shift in the boundary of pelican habitat, reflecting the availability of fish at the time of the bird's arrival in their nesting areas (Wall, 1989).

Woodland caribou that inhabit the park are at their southern limit. Their preferred habitat of coniferous forests would eventually retreat beyond the borders of the park. This will take the small population of caribou out of the park as well (Wall, 1989). However, habitat for bison in the park will increase under global warming conditions. The Bison tend to inhabit the area between grasslands and forests. It is believed that a warming in the future will increase bison habitat in the park (Wall, 1989).

Given the shortened winter and extended summer seasons, there are likely to be impacts on park visitation and potentially net tourism revenues. While winter activities such as cross-country skiing will be diminished, the season for summer activities such as hiking and canoeing will increase (Wall 1998). Should water levels decrease as a result of climatic change the need to portage may increase and canoeing experience / opportunities may diminish. Backcountry and frontcountry camping will experience a similar increase in season length; however, an increase in mosquitoes and flies resulting from milder and wetter spring conditions may curtail popularity in early summer. Park infrastructure and cottages will face higher fire risk, and fire management policies, including campfire bans, may need review.

3.3.4 *Riding Mountain National Park*

Riding Mountain National Park	
DATE ESTABLISHED	1929
LOCATION	Manitoba – Park Geocentroid: 50.86 °N, 100.08 °W
SIZE	2,973 km^2
FEATURES	• Southern Boreal Plains and Plateaux Natural Region • Fescue prairie • Shoal Lake marsh community • Manitoba Escarpment • Snake hibernacula • Okanesse cemetery

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +8.0	SPRING	+4.0 to +26.0
SUMMER	+1.0 to +6.0	SUMMER	-29.0 to +18.0
FALL	+2.0 to +4.0	FALL	-7.0 to +24.0
WINTER	+2.0 to +8.0	WINTER	-9.0 to +14.0

Riding Mountain National Park (RMNP) has been described as an island of forest wilderness surrounded by a sea of agricultural development. Several landforms found within RMNP, include the Saskatchewan Plain, the Manitoba Lowlands and the Manitoba Escarpment (Trant, 1992). The unique attributes of RMNP led to its designation as a UNECO International Biosphere Reserve in 1971.

Climate models suggest regional warming will lead to lowering of local water tables (Larson, 1995). Higher spring precipitation and warmer spring temperatures will contribute to faster snowmelt and greater runoff in spring. With the ground still partially frozen, the large spring precipitation increase may not be able to infiltrate into the ground. Without sufficient groundwater replenishment, summer base flow in rivers and streams will likely be lower and thus water tables will also be affected. Rapid spring runoff may also increase soil and riverbank erosion and sedimentation. Clair *et al.* (1998) projects a total annual increase in runoff of approximately 16% in the region.

A recent study of tree growth rates in the boreal forest supports a scenario of an initial burst of tree growth under global warming (Myneni *et al.*, 1995). Analysis of 1981-1991 weather data indicated an increase in photosynthetic activity as spring came earlier, and fall arrived later. The amount of dieback expected from temperature increases is unknown due to questions of how trees will respond to increased CO_2 availability (Myneni *et al.*, 1997). Understorey species will likely respond faster than trees causing a destabilization of forest ecosystems. Exotic species adapted to higher temperatures will likely invade the understorey, while native species may decline (de Groot and Ketner, 1994).

Herman and Scott (1992) project that, with higher temperatures, boreal species would eventually be replaced by more warmth-tolerant species. Changing environmental conditions will lead to different competition advantages and potentially to the invasion by new species. Species better adapted to higher temperatures and drier conditions, such as C4 species (refer to Grasslands National Park, Section 3.4.2), may threaten existing plant species (de Groot and Ketner, 1994). Grasslands in the park are likely to expand with higher summer temperatures if there is only a marginal increase in summer precipitation. These changes in vegetation can continue to be monitored in the biodiversity plots marked out throughout the park.

Altered fire regimes were identified as a serious problem for RMNP (Parks Canada 1997, 1998). The need for fire to maintain grasslands was also recognized for RMNP. As forest fires are climate dependent, warming is expected to increase fire frequencies and intensities (Suffling and Speller, 1998). For example, a doubling of atmospheric CO_2 may increase the fire weather index ratio by 1.5 to 2.0 times in the RMNP region (Thompson *et al.*, 1998).

Fire disturbance can increase landscape level ecosystem diversity but the transition to a younger forest will affect species that make use of mature forests. Increased fire disturbance may hasten the transition from a boreal to a grassland community in some areas. In addition, the timing of the fire occurrence will also play a vital role in the type of grassland community that is established. Early fires may suppress cold season grasses while late fires suppress warm season grasses.

As vegetation is affected by climate change, wildlife habitats will also evolve. Different species will respond in different ways and at different rates. Small non-hibernating mammals will be more sensitive to factors such as reduced thermal snow protection and increased winter exposure to predation than to increased summer temperatures and desiccation risks (Herman and Scott, 1992). Amphibians and reptiles will be more sensitive to changes in summer factors. Winter changes are unlikely to affect most reptile and amphibian species in hibernation. The snake hibernaculum was identified as having special preservation status, thus monitoring possible climate change impacts on this feature should be considered.

It may be more difficult to protect the larger mammals as disturbances often fragment and modify the landscape, resulting in population isolation and increased mortality. Not all impacts will be negative. Bears, for example, thrive in diverse forest landscapes that result from fires. The estimated 5500 elk within the park also benefit from fires since the lack of fires has made fescue grass tougher and less palatable. Species, such as the reintroduced pine marten and fisher, may be adversely affected by habitat fragmentation and reduction in mature forest area.

The RMNP's size is not sufficient to protect most species found within the park from both human and natural disturbances. As legal land boundaries cannot govern ecosystem processes, the management of lands adjacent to the park will influence the park 's ability

to protect plants and wildlife. The most accepted method of maintaining biological diversity is to preserve effective habitat for all species. Co-operative efforts with surrounding land owners will become ever more important as global warming modifies the RMNP environment.

RMNP attracts many visitors and is culturally rich. An archaeological inventory conducted from 1995 to 1998 identified many culturally significant sites dating back as far as 6,000 years. There is a need to understand the effects of climate change on such sites in order to preserve them. In particular, these sites should be assessed for their vulnerability to increased fire or erosion. Park managers should also be aware of threats to park infrastructure posed by increased fire hazard resulting from climate change. Drier conditions and higher fire hazard may necessitate the review of fire management plans and campfire policies.

The season for summer recreation such as hiking, camping and golfing will be extended, but the season for cross-country and downhill skiing (at the park's eastern boundary) will be curtailed. If increased winter precipitation falls as snow, conditions for winter recreation may improve over the span of a shortened season. Increased irrigation may be required for the golf course to maintain fairways and greens under drier conditions. Also, sports fishermen may notice a shift in the species of fish in the lakes and streams of RMNP toward those more tolerant of warmer water. The impact of climate change on summer water levels within the park is uncertain at this time. However, if increased annual precipitation outweighs increases in evapotranspiration, water recreation may benefit. Higher water levels may negatively impact some park infrastructure such as the Ominik Marsh Trail.

3.3.5 Wood Buffalo National Park

Wood Buffalo National Parke	
DATE ESTABLISHED	1922
LOCATION	Alberta and Northwest Territories – Park Geocentroid: 58.62°N, 112.95°W
SIZE	44,802 km^2
FEATURES	• Southern Boreal Plains and Plateaux Natural Region • UNESCO World Heritage Site • Peace-Athabasca Delta • Great Slave and Great Bear Lake, Mackenzie River • Largest free-roaming herd of bison in the world

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+1.0 to +5.0	SPRING	+2.0 to +31.0
SUMMER	0.0 to +3.0	SUMMER	-8.0 to +23.0
FALL	+1.0 to +6.0	FALL	+7.0 to +27.0
WINTER	+3.0 to +6.0	WINTER	-11.0 to +14.0

Wood Buffalo National Park (WBNP) is a UNESCO World Heritage Site and is the home to one of North America's most extensive landscapes of sinkholes, underground rivers, caves and sunken valleys. The Peace-Athabasca Delta, one of the word's largest inland deltas and a wetland of global significance, also lies within WBNP. Wetland dynamics will be of utmost importance for the protection of the habitats and species of the Peace-Athabasca. WBNP is the only known breeding ground of the endangered whooping crane. Little is known on how climate change will affect this species.

According to de Groot and Ketner (1994), an increase or decrease in water availability could alter species composition of wetland communities. Clair *et al.* (1998) projected a total annual increase in runoff in the region of approximately 16%. Wetland sensitivity to desiccation has been clearly shown by the drainage of lands adjacent to wetlands for agriculture purposes. It should also be noted that water regulation by the WAC Bennett Dam has significant implications for hydrology in the park.

Other significant features in WBNP include two huge lakes, Great Bear and Great Slave, and Canada's largest river, the Mackenzie. It is unclear how climate change will specifically affect these systems. Arguably, with such large increases in precipitation throughout the year, change is certain. Due to the ecological importance of these systems, it is urgent to conduct in this area.

Soil formation is a function of climate, biotic activities, topography, parent material, and time (Brady and Weil, 1996). WBNP is at a transition zone between the boreal and taiga biomes, the type and rate of soil formation may affect vegetation migration as climate conditions change (i.e., soil formation would lag behind the rapid climate change projected in the region).

As WBNP is at the boreal/taiga transition, vegetation varies markedly according to site conditions. In the northern parts of the park, spruce dominates. Here the understorey consists largely of gray-green lichens that provide for caribou during winter. On milder sites, dense forests of spruce mixed with balsam poplar, birch and aspen prevail. In areas with poor drainage, black spruce and tamarack dominate. Extensive karst and treeless landscapes also cover large parts of the region and there are saline soils in places.

Under conditions of warming, Herman and Scott (1992) project boreal habitats in the area would eventually disappear and be replaced by more warmth-tolerant species. However, the actual extent of dieback is unknown due to uncertainty of tree response to increased carbon dioxide. Myneni *et al.* (1997) suggested there would be an initial burst of tree growth under climate warming.

It is also essential to note the disjuncture between the rate of projected change and the ability of species to adapt and migrate to areas with suitable climate conditions. The potential shift of the northern boreal boundary (the 60 growing degree-day isoline) ranges

from 100-700 km (Wheaton *et al.*, 1988). Species, such as white spruce, can only move 3-4 km every 40 years. According to Rowe (1989:3), with the possible exception of birch and poplar, boreal trees '... can't gallop along that fast.'

Biome shifts and the loss of old-growth forests through forest fires will decrease the likelihood of survival for many wildlife species dependent on the boreal forest. For example, the area of boreal forest that provides important winter shelter and food for caribou will likely be reduced due to the expansion of the Aspen Parkland.

Forest fires, being climate dependent, will likely respond to a rise in temperature with increased frequencies and intensities (Suffling and Speller, 1998). According to Thompson *et al.* (1998), a doubling of atmospheric CO_2 may increase the fire weather index by a factor of one in the region. However, Kadonaga (1997) projects an increase in the FWI of between 2.4 and 4.3 in May and June, 1.1 to 1.4 in July and 2.3 to 2.8 in August (depending on the GCM used). Plants with wind blown seeds are usually the first to re-establish after a fire. Although forest fires help replenish soil nutrients and foster forest diversity, fire disturbance may lead to loss of mature forest, habitat fragmentation and inhibition of species migration. The implications of an altered forest fire regime will therefore be positive for some species and detrimental to others.

WBNP is currently a relatively undisturbed wildland area. Aboriginal people continue to hunt, trap and fish within the park. Climate change impacts wildlife will therefore also influence aboriginal lifestyles. There are currently 344 known archaeological sites within WBNP. The potential threat to these sites from hydrological changes is uncertain.

The length of the season for summer recreation pursuits, such as canoeing, fishing, camping and hiking, should increase. Increases in mosquitoes and flies as a result of wetter and milder conditions may curtail the popularity of some activities, especially early in the season. The anticipated increase in annual runoff may enhance opportunities for canoeing, facilitating access with higher water levels. Higher water levels, increased runoff and warmer water temperatures may increase sport-fishing opportunities if aquatic ecosystems respond with increased productivity. The length of the season for winter recreation such as snowshoeing and cross-country skiing may decrease with milder conditions. However, the warmer winter temperatures may increase recreational opportunities despite this shorter season.

3.4 Western Cordillera Parks

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While not likely to see the magnitude of latitudinal species shifts of some other regions, parks in the Western Cordillera region will be the most susceptible to elevational shifts. Species of the high-elevation alpine and sub-alpine zones of the Western Cordillera mountains are at their limits in terms of tolerance of environmental conditions. A mean annual temperature increase of only 3°C would shift competitive interactions among species and is expected to translate into an approximate upward shift of the alpine-subalpine ecotone by 500 to 600 metres. With projected temperature increases, National Parks in the Waterton Lakes to Jasper complex are likely to experience some loss of alpine assemblages from mountain peaks.

Mean winter temperatures would remain below freezing in all GCM scenarios, thus additional winter precipitation will likely increase the snow pack (though it would likely persist for a shorter time). An increased snow pack has implications for avalanche activity (with both human safety and ecological disturbance impacts), glacial mass balance, and the winter range of several large mammals. Low elevation glaciers in the region are projected to thin and retreat. Glaciers less than 100m thick could disappear over the next 20 years (Brugman *et al.*, 1997). Altered hydrology from enhanced glacial ablation and altered spring freshet (June instead of May) would have implications for river ecology and recreation.

Forest fire, disease outbreak and insect infestations are likely to increase in the Western Cordillera parks. The ecological consequences of these intensified forest disturbances in the complex topography of region are still largely uncertain.

The effect of CO_2 enrichment is postulated to be greater for high-altitude plants and therefore of possible significance for mountain ecosystems (Price and Haslett, 1995). Understanding of this phenomena and interactions with other climate change related impacts remains limited.

3.4.1 *Banff National Park*

Banff National Park			
DATE ESTABLISHED	1885		
LOCATION	Alberta – Park Geocentroid: 51.28°N, 115.73°W		
SIZE	6,641 km²		
FEATURES	• Rocky Mountains Natural Region • UNESCO World Heritage Site (Four Mountain Parks) • Sulphur Mountain Hot Springs • Castleguard Cave System and meadows • Grizzly bear habitat • Tourism destination of the Park and of the Town of Banff • Cave and Basin Marsh		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +6.0	SPRING	+3.0 to +19.0
SUMMER	+1.0 to +4.0	SUMMER	-13.0 to –1.0
FALL	+2.0 to +3.0	FALL	-1.0 to +13.0
WINTER	+2.0 to +6.0	WINTER	+2.0 to +33.0

Banff is the oldest of Canada's National Parks. Located in the south central Rocky Mountains of Alberta, Banff demonstrates unique ecological features. Banff's hydrological resources include springs, streams, rivers and lakes. The most famous spring at Sulphur Mountain is completely dependent upon precipitation. Climate change projections for Banff National Park (BNP) indicate that winter and spring precipitation is expected to increase, while summer precipitation is expected to decrease.

Warmer spring and fall temperatures will extend the melting season of glaciers by at least one month in the southern Rocky Mountains. Lower elevation glaciers, such as the Peyto, are projected to retreat rapidly as a result of projected climate warming (Brugmann *et al.*, 1997). Accelerated glacial retreat would increase summer runoff until the glaciers have been largely depleted. Blais *et al.* (1998) observed high concentrations of persistent organochlorine compounds in glacial ice and snow in the mountain ranges of Western Canada (concentrations were elevated 10 to 100-fold between 770 and 3100m elevation). These pollutants have accumulated over decades via long-range air transport. A rapid glacial melt may release these trapped pollutants in sufficient quantities to be of concern for downstream aquatic ecosystems.

With these changes in glacial balance, the water level in the Sulphur Mountain Hot Springs are expected to remain near current levels or decrease slightly. The Columbia Icefield influences the karst aquifer of the Castleguard Spring (Achuff and Pengelly, 1986). As a result of the projected increase in both winter and spring precipitation and in mean annual temperature, some of the snow pack at high elevations and in glaciers is expected to melt. The level of the Castleguard Spring is thus expected to increase.

The waterfall systems, by comparison are affected by stream and river levels. The increase in winter precipitation will again play a role, this time by increasing stream and river levels during spring run-off. Total annual runoff in the montane region is projected to increase by approximately 21%, with peak flows occurring a month earlier (Clair *et al.*, 1998). The accelerated retreat of smaller, low elevation glaciers will be partly responsible for this increase. As these glaciers melt, late summer flow could be augmented, increasing the likelihood of flooding. However, once these glaciers have melted, input to streams could decrease substantially within only a few years (Brugmann *et al.*, 1997).

The increased runoff will result in increased sediment transport through the alpine, subalpine and montane lake systems of the park. With the increase in winter precipitation, erosion and weathering are expected to increase. Sediment transport will also increase, resulting in an increase in water turbidity in the park's lakes and streams. Bank erosion, especially in the Bow River channel, may have consequences for park infrastructure. Potential impacts of climate change should be considered when modifications are made to existing structures or new ones are planned.

The alpine lakes are typically oligotrophic (Achuff and Pengelly, 1986) with low temperatures and short growing seasons. An increase in mean annual temperature may slightly increase lake temperatures. However, it is unlikely that these glacial-fed water bodies will warm sufficiently to change growth patterns of aquatic species. Water levels in the subalpine lakes, which are mostly glacial-fed, may increase, with consequent increased erosion in littoral zones. The warmer temperature throughout the year is also expected to increase the ice-free season of alpine, subalpine and montane lakes. The Vermillion Lakes Wetland Area (VLWA) is extremely sensitive to impact due to its sensitivity to water level changes. Projected changes in precipitation and temperature throughout the year could have a significant impact on this sensitive area. The projected decrease in flow in the Bow River during the late summer and fall months will affect the water supply for communities downstream, including the City of Calgary. This decrease in water flow may result in increased pressure for water control devices (e.g., dams) to be built in or near the park, which in turn might affect Banff natural water flow.

Banff National Park contains montane, subalpine and alpine vegetation zones. Forty-one plant species reach their range limits in the park, and are therefore particularly sensitive to climate change. Both latitudinal and elevational boundary shifts should be expected. A temperature increase of between 1 and 6°C will cause vegetation zones to shift upwards by approximately 500 to 600 metres, the equivalent of one vegetative zone in mountainous regions (Stone, 1996). This shift of species may result in the loss of some alpine species that will be unable to compete with subalpine or montane species that expand upward. In one study, MacDonald and Brown (1992) modelled the loss of mammals in montane habitats from climate change and predicted that an increase of 3°C would result in species losses of 9 to 62% from mountaintops. These changes could result in a net loss of biodiversity in Banff National Park as mountain peaks are denuded of high altitude plant species. Zolbrod and Peterson (1999) modelled the response of high-altitude forests to projected climate change and found impacts differed significantly

depending on mesoscale (orographic effects) and microscale (north-south facing slopes) factors. Consequently, impact assessment in areas of complex topography will need to be conducted at a finer spatial scale before more detailed conclusions can be drawn for each national park in this region.

The migration of animals and birds through the park will also be significantly affected by climate change. The current wintering zone for the park's ungulate herds is the Bow Valley. Located in the montane region of the park, this area provides a shallower snow pack, allowing these animals to move with relative ease. The movements of deer and bighorn sheep are restricted with snow depths of about 50cm, and elk at about 75cm. (Harding and McCallum, 1997). The projected increase in winter precipitation of between 2 and 17% may impair the movement of these species. Also, greater risk of formation of a hard crust on the snow surface after a freezing rain or rain on snow event may increase hardship on ungulate populations. In response to these changes, ungulates in the Bow Valley may migrate down valley to find food throughout the winter. The area downstream in the Bow valley is, however, the focus of intense land development. The Trans Canada Highway and the Canadian Pacific Railway (CPR) transect Banff National Park. This transportation corridor plays a significant role in wildlife mortality. Although a fence has been erected along the length of the highway and animal crossings (over and under passes) added, the CPR remains an issue. With an increasing need for large mammals to escape an increasing snow pack by moving into the lower elevations of the park, mortality in this area may increase.

The fire regime of Banff National Park will be affected by climate change. Forest fires are projected to become more frequent in the region. The intensity of fires may also increase as a result of drier summer conditions. This will result in the need for greater protection of property while at the same time attempting to restore the park's natural fire regime. Increased incidence of forest pests may exacerbate the fire hazard. Higher summer temperatures and less severe winter cold spells are expected to increase forest disease and insect attack, such as species of bark beetle on lodgepole pine communities and high elevation spruce and fir forests (Harding and McCullum, 1997). Fires could become more intense when they occur in forest stands affected by these insect species.

The impact of climate change on downhill skiing in western Canada has not been adequately studied. An increase in winter snowfall may result in better ski conditions, however warmer temperatures in late fall and early spring may result in a shortened season. This could have important implications for tourist revenue if the loss of skiers during the Christmas ski peak (due to poor snow conditions) outweighs any increase in skiers attracted by milder conditions. In addition, increased temperatures may push quality ski conditions to higher elevations, potentially increasing the pressure to expand area ski facilities upward. The potential increase in avalanche activity due to increases in snow pack and higher winter temperatures may increase the disruption of ski operations, highway and rail corridors in the park. Warmer temperatures are expected to increase the length of the summer season for activities including hiking, camping, golfing and rafting.

Deeper snowpack may continue to restrict the accessibility of some high elevation trails; however, trails in lower areas will experience a similar increase in season length. Higher stream water levels may impede backcountry trail users and, at times, pose an extra risk to visitors. Rafting may benefit from higher late summer water levels resulting from increased glacial melting, as long as there is a large enough volume of ice to still be melted. Higher spring peak flows, however, may threaten park infrastructure such as bridges, culverts and trails. Decreased summer precipitation and higher evapotranspiration rates may increase irrigation requirements for golf courses.

This increase in the level of summer visitors to the park will increase impacts to sensitive park ecosystems (e.g., erosion of trails to popular sites). The potential increase in revenue from a longer summer season may offset some of the lost revenue from a shorter winter recreation season. Increased forest fire hazard may necessitate a review of park fire management plans and possible limits on recreational access or campfire policies.

3.4.2 Glacier National Park and Mount Revelstoke National Park

Glacier National Park		Mount Revelstoke National Park	
DATE EST.	1886	DATE EST.	1914
LOCATION	British Columbia – Park Geocentroid: 51.28°N, 117.50°W	LOCATION	British Columbia – Park Geocentroid: 51.11°N, 117.98°W
SIZE	1,349 km^2	SIZE	259 km^2
FEATURES	• Rocky Mountains Natural Region • 400 glaciers/glacierets • Significant avalanche activity throughout the winter • Nakimu and Mount Tupper Cave systems • Alpine tundra and subalpine ecoregions • Small area of cedar-hemlock rainforest	FEATURES	• Rocky Mountains Natural Region • Significant avalanche activity throughout the winter • Alpine tundra and subalpine ecosystems grading to cedar-pine rainforest at the valley bottom.

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +5.0	SPRING	-4.0 to +9.0
SUMMER	+1.0 to +3.0	SUMMER	-13.0 to -3.0
FALL	+2.0 to +3.0	FALL	-1.0 to +25.0
WINTER	+2.0 to +5.0	WINTER	+5.0 to +25.0

Glacier National Park and Mount Revelstoke National Park are located within the Columbia Mountain Range of Southeastern British Columbia. Over half of Glacier National Park is characterized by the alpine ecosystem, while the remainder is subalpine forest and mountain meadows. Mt. Revelstoke National Park encompasses a variety of ecological zones from tundra and alpine meadows to subalpine forests, down to a dense rainforest of cedar and pine.

The steep slopes of the Selkirk and Purcell mountain ranges provide for active glaciers and much avalanche activity in both Mount Revelstoke and Glacier National Parks. The Illecillewaet glacier in Glacier National Park is among the 400 glaciers and glacierets found within the Park boundary. Brugmann *et al.* (1997) predicted low elevation glaciers would experience rapid retreat, while glaciers with higher accumulation zones, such as the Illecillewaet glacier, will retreat less rapidly or even advance slowly with projected higher winter snowfall increases.

As a result of higher winter and spring precipitation, runoff and ground water levels would rise in the spring and peak flows would likely occur one month earlier, in June rather than in July (Coulson, 1997). The winter snowpack is expected to become deeper in response to a 2 to 25% increase in winter precipitation. This will result in heavier spring floodwaters. Clair *et al.* (1998) project that total annual runoff in the montane region will increase approximately 21% and peak runoff occur in May instead of June. The accelerated retreat of smaller, low elevation glaciers will be partly responsible for this increase; however, once these glaciers have melted, input to streams could suddenly decrease within only a few years (Brugmann *et al.*, 1997). As these small glaciers melt, late summer flow could be augmented, increasing the likelihood of more late summer and fall floods. Changed hydrology may alter the habitat of aquatic species as a result of physical changes to park areas (e.g., flooding of a wetland or erosion of a riverbank).

The magnitude and frequency of avalanches is expected to increase due to the increase in and fluctuation of winter temperatures (Evans and Clague, 1997). The projected increase in winter temperatures is expected to lead to unstable layers in the snow pack, triggering increased avalanche activity throughout the winter. The increased avalanche activity will cut longer and wider meadows in sub-alpine forests, as well as dump more debris into stream courses. The open meadows created by avalanches will provide increased habitat for some wildlife, such as the hoary marmot. However, an increase in avalanche activity is a human hazard, both in the backcountry (where winter recreation is likely to increase due to warmer winter temperatures) and along the Trans Canada Highway.

Increased melting at higher altitudes during the spring and summer months will increase erosion and sediment transportation in streams and rivers. Exposure of moraine deposits and removal of the buttressing support of glacial ice on valley walls may result in increased slope instability. This may result in increased debris or mass movement flows, (Evans and Clague, 1997).

The projected decrease in summer precipitation of 3 to 13% is significant. With the projected accompanying summer temperature increase of 1 to 5°C, evaporation from lakes, rivers, and streams is expected to rise. An increase in evaporation will decrease groundwater recharge (Stone, 1996). More important, this increase in evaporation will decrease runoff to lower, more arid regions, which will be looking for security of water supply. This effect will become pronounced after the small low-lying glaciers have

largely melted. This trend may result in increased pressure for water control devices to be built in these parks.

Increasing summer temperatures and less severe winter cold spells are expected to increase forest disease and insect attack, such as species of bark beetle on lodgepole pine communities and high elevation spruce and fir forests (Harding and McCullum, 1997). The likelihood of drought and forest fires will also be greater as a result of the hotter, drier summers. However, lengthened avalanche tracks may limit the spread of fires (Suffling, 1993). Further discussion of potential changes in fire regime can be found in the discussion on Banff National Park (Section 3.4.1).

With projected changes in temperature and precipitation, there is potential for elevational shifts in the ecotone between alpine and subalpine zones. This would decrease the size of the alpine ecosystem, resulting in a smaller habitat area for the alpine species (Hebda, 1997). A 3°C increase in temperature will result in the shift of alpine-subalpine ecotone upward by approximately 500 to 600 metres (Stone, 1996). The subalpine and mountain meadow ecosystems will increase in size, with their boundaries increasing in altitude. This will be facilitated by increased avalanche activity clearing paths along the alpine slopes (Suffling, 1993). Such changes are significant and may result in the extirpation of some alpine species that are unable to adapt. Some alpine species, for example, "respond to warming with a migration rate of only 1 to 4 [vertical] metres per decade" (Markham and Loh, 1996:51).

Relatively few large animals winter in these parks due to the deep winter snowpack. The increase in winter precipitation will increase this snowpack and warmer winter temperatures could cause more icy conditions. Thus, browse may become more difficult to find and a higher amount of energy would be required for mobility. In addition, the projected increase in spring floodwaters due to an increase in winter precipitation may significantly affect movement of wildlife throughout the park.

The small area of cedar-hemlock rainforest at the base of the valley in Glacier National Park and the cedar-pine rainforest in Mt. Revelstoke National Park exist due to the current high year-round precipitation in those locations. Drier conditions resulting from a projected decrease in summer precipitation and increase in summer temperature may stress these ecosystems.

With warmer temperatures projected throughout the year, an increase in the number of park users is expected. Increased forest fire hazard may necessitate a review of park fire management plans and possible limits on recreational access or campfire policies. Backcountry winter recreation activities should also be evaluated for increased risk from avalanches. Higher spring peak flow in streams may destroy park infrastructure (e.g., bridges) and impede recreational travellers. However, lower summer precipitation and increased evapotranspiration will likely decrease water levels, potentially limiting river-based recreation.

3.4.3 *Jasper National Park*

Jasper National Park	
DATE ESTABLISHED	1907
LOCATION	Alberta – Park Geocentroid: 52.89°N, 118.04°W
SIZE	10,878 km^2
FEATURES	• Rocky Mountains Natural Region • Highest mountain in Alberta (Mt. Columbia 3747 m) • Hydrographic apex of North America (Columbia Icefield) • Longest underground drainage system known in Canada (Maligne Valley Karst) • Only sand-dune ecosystem in four Mountain Parks (Jasper Lake) • Northern limit in Alberta of the Douglas fir (Brûlé Lake)

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +5.0	SPRING	+3.0 to +13.0
SUMMER	+2.0 to +3.0	SUMMER	-13.0 to +7.0
FALL	+2.0 to +3.0	FALL	-1.0 to +28.0
WINTER	+2.0 to +5.0	WINTER	+2.0 to +25.0

Jasper National Park is part of the UNESCO Four Mountain Parks World Heritage Site (the other parks include Banff, Yoho, Kootenay). Located in west central Alberta on the eastern slopes of the Rocky Mountains, Jasper is the largest and most northerly of the four parks.

The area of glaciers and icefields in the southern Canadian Rocky Mountains has been estimated to have decreased by as much as 25% between 1850 and 1992 (Luckman 1998). In the face of climate change, the levels of winter precipitation in Jasper National Park are expected to increase by between 2 and 25%. The net effect of projected climate change on the mass balance of the glaciers in this region is largely dependent on the elevation of the glacial accumulation zones. Lower elevation glaciers will likely experience rapid retreat. Higher elevation glaciers with large accumulation zones, like the Columbia Icefields, will be less affected as they would continue to receive enough snow in winter to offset enhanced summer melting (Brugmann *et al.*, 1997).

The relationship between precipitation and stream flow regimes is complex over a large mountain catchment basin such as Jasper's (Luckman, 1998). The projected increase in winter precipitation will create a deeper snow pack throughout Jasper National Park. As a result, the volume of peak spring run-off will be greater and occur in May rather than June (Clair *et al.*, 1998). Between the increased annual precipitation and the accelerated melting of glaciers, total annual runoff in the region is projected to increase approximately 21% (Clair *et al.*, 1998). The accelerated retreat of smaller, low elevation glaciers will be partly responsible for this increase; however, once these glaciers have melted, input to streams could suddenly decrease within only a few years (Brugmann *et al.*, 1997). As

these glaciers melt, late summer flow could be augmented, increasing the likelihood of more late summer and fall floods.

Increased flow will enhance erosion and sediment transport throughout the park. This, in turn, will increase the size of depositional features, such as the alluvial fans and deltas (e.g., Samson Narrows of Maligne Lake). The Athabasca River (which drains 80% of Jasper National Park), the Maligne River-Medicine Lake Karst system, and Jasper's other rivers are expected to experience an increase in both water levels and velocity. Medicine Lake, a unique, intermittent lake in Jasper National Park, is expected to have higher water levels year-round with projected climate change, and other lakes will rise.

Jasper Lake, the only sand dune system in the Canadian Rocky Mountains, is extremely sensitive to wind erosion. Due to the harsh growing conditions, damaged vegetation takes a long time to recover. With an increase in precipitation and run-off, the dunes would be more sensitive to water erosion. Otherwise, warmer and drier summer conditions may promote the expansion of the dune complex, particularly if down valley wind speeds increase due to the increased gradient between the cool air over glaciers and warm valley air.

The northern limit of the Douglas fir is also found in Jasper National Park at Brulé Lake. With increasing temperatures, the northern boundary for this species may move further north, but only if protected low altitude corridors exist to connect these areas. A 3°C increase in temperature will result in the shift of alpine-subalpine ecotone upward by approximately 500 to 600 metres (Stone, 1996). As a result, the vegetation presently found in the habitats of highest altitude may be lost as new species migrate. These elevational shifts may be "constrained by limitations in soil conditions, water availability, permafrost, and insufficient amounts of sunshine" (Chiotti, 1998:387). A loss of biodiversity due to the extinction of high alpine species may also be a significant result of climate change (refer to discussion on Banff National Park - Section 3.5.1).

Deeper snow – due to the projected 2 to 25% increase in winter precipitation – will provide a haven for small plants and mammals throughout the winter. When air temperatures are – 40°C, temperatures under a deep snow pack can be as warm as – 7°C, protecting smaller living creatures throughout the harsh winter months. Deeper snow will restrict the movement of large mammals in their current winter range. The Jasper Lake system is particularly important to elk and mule deer during winter as it provides relief from the restrictions to movement of deep snow at higher altitudes. The projected increase in winter precipitation of between 2 and 25% would further restrict large mammal movement even in the montane regions of the park, particularly if rain or freezing rain formed a crust of ice on the snow surface. Easterly migration – out of the park to the plains - may be required for these animals to find food and safety from predators throughout the winter.

The increasing summer temperatures and decreasing summer precipitation are expected to increase the frequency and intensity of fire in Jasper National Park. The probable high intensity of many fires will reflect previous fire suppression policies (refer to discussion regarding fire intensity in Banff National Park - Section 3.5.1). Increasing summer temperatures and less severe winter cold spells are expected to increase forest disease and insect attack, such as species of bark beetle on lodgepole pine communities and high elevation spruce and fir forests (Harding and McCullum, 1997). Thus, fuel accumulation for forest fires may increase. The combination of increased insect and disease attacks and fires would open up the forest canopy for ground vegetation and would provide greater habitat for ungulate species and meadow plants.

Climate change will also have numerous implications for human activity and infrastructure within the park. The Canadian National Railway, the Trans-Canada Highway and the Trans-Mountain Pipelines all cross Jasper National Park. The deeper snowpack, increased flooding and erosion in the spring and summer may damage this infrastructure, as may more frequent, unexpected avalanches and debris flows (e.g., the closure of the Trans-Canada near Banff in the summer of 1999 from a large mud flow). The possibility of changed migration patterns of park wildlife may also affect mortality on highways and railways as more mammals attempt to move from the deeper winter snow pack.

With warmer temperatures year-round and an increased amount of snow expected, the effect on the ski season is uncertain. Research to examine the implications for ski conditions and the length of season are recommended (also refer to discussion of Banff National Park - Section 3.5.1). Ski operations and backcountry winter recreation will also be at a greater risk from increased avalanche activity. In general, the length of the season for summer activities such as golf, hiking, camping and rafting is expected to increase at the expense of the winter recreation season. Accessibility of hiking trails could increase, except for higher elevation areas which are likely to experience increased snowpack. Increased late summer water levels due to enhanced glacial melting will likely increase opportunities for rafting and other river-based recreation. However, swollen meltwater streams may restrict recreational access to some areas and threaten park infrastructure such as trails, culverts and bridges.

3.4.4 *Kootenay National Park*

Kootenay National Park	
DATE ESTABLISHED	1920
LOCATION	B.C.-Alberta Border – Park Geocentroid: 50.88°N, 116.03°W
SIZE	1,406 km^2
FEATURES	• Rocky Mountains Natural Region • Ochre beds of the Vermillion River Valley • Talc deposits at Natalko Lake • Dry Gulch-Stoddart Creek Douglas fir - ponderosa pine - wheatgrass community • Radium Hot Springs • Paint Pot mineral springs • UNESCO World Heritage Site

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +5.0	SPRING	+1.0 to +10.0
SUMMER	+1.0 to +3.0	SUMMER	-13.0 to +2.0
FALL	+2.0 to +3.0	FALL	-1.0 to +23.0
WINTER	+2.0 to +5.0	WINTER	+2.0 to +24.0

Kootenay National Park is located next to both Banff and Yoho National Parks and is part of the UNESCO Four Mountain Parks World Heritage site. As with the other mountain parks, climate change projections for Kootenay National Park indicate an annual increase in temperature with a seasonal variation in precipitation.

Winter months are expected to bring a significant increase in precipitation of between 2 and 24%, accompanied by temperature increases of between 2 and 5°C. Increased winter temperatures will bring more rapid melting of the snow pack throughout the park. A more rapid melt would increase the level and velocity of streams and rivers, including the Vermillion, Simpson and Kootenay Rivers, which eventually lead to the Columbia River. Avalanche and debris flow activity is also expected to increase due to the warmer conditions and increased snowpack projected for the winter months.

The increase in surface water flow may alter ground water recharge throughout Kootenay National Park. Radium Hot Springs and the Paint Pot mineral springs may be affected by this change. The increased flow of the rivers in the park will enhance erosion and sediment transport, during peak flow periods, in the spring and summer. As a result, deposition in the alluvial fans at Hawk and Floe Creeks will increase.

The fragile ochre beds in the Vermillion River Valley and talc deposits at Natalko Lake may also be affected by climate change. The increase in melt water due to the increase in both winter precipitation and annual temperature may increase erosion of these sites. The fossil beds of the Stephen Formation, and the Ice River igneous complex should also be monitored for the effects of erosion.

Kootenay National Park hosts various species at the limits of their ranges. The western hemlock, western larch and ponderosa pine are Pacific species at their eastern and northern limits in the park. The Dry Gulch-Stoddart Creek area has a drier, warmer climate than the rest of the Park and is the only Douglas fir/ponderosa pine/wheatgrass ecosystem in the Canadian Rocky Mountains. With increased summer temperatures and decreased levels of precipitation in the summer months, this area may expand.

Although climate change may increase the habitat for some plants in the park, other species may be lost. Particularly vulnerable are the alpine species at the highest elevations. A mean annual temperature increase of 3°C will result in a 500 to 600 m upward shift of vegetation habitat (Stone, 1996). Increased temperature and decreased precipitation in summer may also increase the habitat area for invasive species such as knapweed and Russian thistle.

Both fire disturbance, due to increasing summer temperatures with an accompanying decrease in summer precipitation, and mountain pine beetle invasions are expected to increase in Kootenay National Park (Harding and McCullum, 1997). These disturbances, along with the increased potential for disease in the park's forest communities, could cause major changes to the park's current forest condition. Attempts to restore a natural fire regime in Kootenay National Park should consider potential climate change impacts through revised forest fire management plans (see Suffling, 1991 on maintaining fire regimes in parks in the face of climate change).

Kootenay National Park is home to 57 species of mammals, 191 birds, 4 amphibians, and 3 reptiles. Protection of these species requires protection of their habitats. Climate change impacts will result in the migration of a number of these species northward and/or to higher altitudes during the summer months (or permanently in some cases). The increase in winter precipitation will result in more restricted movement for large animals who may have to shift their wintering ranges south or to lower altitudes. This seasonal animal movement will have effects on highway mortality rates for migratory species (see Banff National Park and Jasper National Park – Sections 3.4.1 and 3.4.3 respectively).

The numbers of recreation users is expected to increase during the shorter winter season due to the more favourable climatic conditions. The combination of projected increase in avalanches and debris flows as well as higher traffic along Highway 93 will increase risk to motorists. Likewise, backcountry users will face higher avalanche risks. The more favourable climate is also expected to increase the length of the summer tourism season in the park. Seasons for camping, hiking and river recreation are all expected to increase in length with warmer temperatures. However, backcountry use and campfire policies may need to be reviewed in view of increased forest fire risk in the summer. Any adverse impacts on the Radium and Pain Pot hot springs would negatively effect park tourism. An inventory of archaeological sites in Kootenay National Park was recommended in the Management Plan in 1988. As these sites are identified, protection from possible impacts of climate change and increased human use should be considered.

3.4.5 *Nahanni National Park Reserve*

Nahanni National Park Reserve	
DATE ESTABLISHED	1976
LOCATION	Northwest Territories – Park Geocentroid: 61.53°N, 125.57°W
SIZE	4,766 km^2
FEATURES	• Mackenzie Mountains Natural Region • Rugged mountains, caves, canyons, hot sulphur springs, and turbulent rivers dominate the landscape • Dall's sheep, trumpeter swans, grizzly bears, mountain goats, peregrine falcons, wood bison and wolverines inhabit the area • Vegetation characterized by lowland, montane, subalpine and alpine tundra ecoregions • UNESCO World Heritage Site designation

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	+5.0 to +28.0
SUMMER	+2.0 to +4.0	SUMMER	-12.0 to +51.0
FALL	+1.0 to +3.0	FALL	+10.0 to +58.0
WINTER	+3.0 to +6.0	WINTER	+10.0 to +33.0

Nahanni National Park Reserve is located on the eastern edge of the Mackenzie Mountains in a landscape dominated by the drainage of the Flat and South Nahanni Rivers. The western edges of the park encompass high, snow-covered peaks and glaciers, while the east half protects the fringe of montane and lowland vegetation communities (Parks Canada, 1983). The weather systems in Nahanni are highly variable, given its position on the boundary between Pacific and Arctic air masses. The projected increase in temperature and precipitation are likely to have a significant impact on the ecological resources of the park.

Changes in the runoff for the South Nahanni River would have far reaching effects on the park. Spring peak flows will likely occur slightly earlier in the year (Cohen, 1997). According to one hydrological model, runoff under doubled-CO_2 resembled present conditions (Staple and Wall, 1996). In other words, the net effect of increased glacial melting, increased snow-pack and rainfall would balance increased evaporation, transpiration and storage in the area. Additional research and close monitoring should be implemented to validate this projection. Significant nesting ponds for the Trumpeter swan along the South Nahanni River and the low-lying Nahanni hotsprings could easily be impacted by a change in peak flow. In addition, the risk to canoeists and white-water rafters could be heightened (Staple, 1994).

The hydrology of Nahanni will also be modified by changes in freeze-up and break-up dates. As temperatures rise, the onset of ice cover on the South Nahanni River and its tributaries will be delayed and the melting of ice will be accelerated. Break-up of river

ice would likely begin in mid-April and freeze-up would likely begin in early November (Cohen, 1997). In some places, warmer temperatures may reduce bottom anchored river ice. As a result, more aquatic habitat may open up with the increase in unfrozen water below the ice cover. Although water temperatures will rise, dissolved oxygen will not be significantly affected due to the turbulent flow of streams and rivers in the area. This could result in an increase in productivity in aquatic ecosystems, possibly leading to larger fish stocks.

With greater warming of lowland areas compared to the glacially cooled mountains to the west, there will likely be an increase in down-valley winds. The increase in winds may result in the expansion and increased erosion of the sand blowouts located at the Southeastern end of the park. The projected increase in temperature and precipitation would also affect the extensive karst landscape including Grotte Valerie. This limestone deposit has been dissolved over hundreds of thousands of years to form one of the best examples of sub-Arctic karst topography in the world (Parks Canada, 1983). The increase in groundwater flow and temperatures will likely accelerate the chemical weathering processes.

The discontinuous permafrost, which is currently common above 3,500 feet (Addison, 1974), may reduce in extent as the lower elevations become too mild to support the frozen ground over the warm season. The thickness of the active layer would likely increase, altering site conditions for plant growth (Maxwell, 1997). This melting, along with projected increases in summer precipitation, could increase the frequency and magnitude of catastrophic slope processes such as rock avalanches and landslides (Svoboda, 1995).

The primary productivity of vegetation will likely increase as warmer temperatures and increased precipitation produce better growing conditions throughout the area. Plant communities will shift elevationally in addition to the latitudinal change. Curran (1991) projected a 100 kilometre northward shift of ecological zones with each 1°C rise in average temperature. The lowland and montane zones will expand up the slopes, with the subalpine and alpine tundra zones facing a reduction in size as a lack of colonizable areas restrict their migration (Staple and Wall, 1996). Black spruce stands will probably be displaced by mixed-wood forests, balsam fir, white pine and white spruce characteristic of a cool temperate ecoclimatic province (Staple, 1994). The up-slope shift of forest communities may decrease the open habitat for grizzly bear and Dall's sheep, but increases in avalanches may provide more subalpine meadow habitat. Wolves may benefit from the increased habitat for prey populations such as white-tailed and mule deer.

Forest fire disturbance in NNP is also expected to increase. With increased summer temperatures the drying of fuels could be accelerated, resulting in an increased fire hazard. Cohen (1997) estimated the annual area burned in the Mackenzie Basin could double under doubled-CO_2 scenarios. An increase in the frequency and severity of thunderstorms would provide more ignition sources for fires. Fire is an important process

in the boreal forest systems, providing for diversity of habitats used by many animals (Forest Fire Review Panel, 1980). Fires can also threaten park and neighbouring infrastructure and resources. The notable increases in summer precipitation (projected by 3 of 4 doubled-CO_2 GCMs) could partially mitigate the factors leading to increased forest fires risk.

Forests will also be affected by an increase in disease and pests under warmer, wetter conditions. In particular, models of white pine weevil hazard project an increase from low to high hazard and expand its range to occupy all areas that presently contain white spruce by 2050 (Sieben *et al.*, 1997). This disturbance will add to the instability of Nahanni ecoregions with a shift to more southern species, as conditions become milder.

The rise in precipitation will likely also lead to an increase in the number and size of wetlands and muskeg. This would benefit species such as moose and beaver inhabiting this zone. However, the increased snow cover in Nahanni may be a threat to ungulates and other wildlife. Deep snow-pack results in less available forage and decreased mobility. It has been suggested with woodland caribou, for instance, that the winter range is the factor limiting population size (Parks Canada, 1983). Overall, the effect of changing winter conditions on caribou will likely be increased hardship over a decreased time period (i.e., a harsher, but shorter winter) (Russell, 1993). Ungulates will also be faced with increased populations of insect pests such as mosquitoes and blackflies resulting from warmer, wetter springs coupled with longer summer seasons. Mosquito season will be shifted earlier as temperatures reach the 7°C minimum emergence temperature and the 18°C peak temperature sooner in the year. Blackfly populations will increase over the summer and survive longer into the fall until a sudden drop in temperature reduces their numbers (Russell, 1993).

Visitation to NNP will likely increase with a warmer and longer summers, with a possible extension of the visitor season by four weeks in the fall (Staple, 1994). An increase in mosquito and blackfly populations may further detract from some visitor experiences within the park. Climate change will not have a significant impact on many of the features people come to see, although it is uncertain if an increase in groundwater could alter the discharge and temperatures of the hot springs. While water levels may remain consistent, white-water rafting will probably take place in a modified environmental setting (Staple and Wall, 1996). A potential increase in the area of forests burned and the shifting of ecological zones could significantly affect hiking, landscape viewing and nature photography (Staple 1994). The increase in visitor use will result in greater impact on park ecosystems. Visitor safety and resource protection will also be an increasing problem for park managers. For instance, hazard assessments should be completed for slope processes such as landslides, rock avalanches and river travel.

3.4.6 *Waterton Lakes National Park*

Waterton Lakes National Park	
DATE ESTABLISHED	1895
LOCATION	Alberta – Park Geocentroid: 49.06°N, 114.05°W
SIZE	1,095 km²
FEATURES	• Rocky Mountains Natural Region • Waterton-Glacier International Peace Park, established in 1932 • Lewis Overthrust (responsible for abrupt meeting of prairies and mountains) • Upper Waterton Lake (Largest glacial trough lake in Canada) • Fescue prairie (only example of this ecoregion protected in a Canadian National Park)

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +6.0	SPRING	+5.0 to +19.0
SUMMER	+1.0 to +4.0	SUMMER	-11.0 to -1.0
FALL	+2.0 to +3.0	FALL	-3.0 to +13.0
WINTER	+3.0 to +6.0	WINTER	+2.0 to +33.0

The abrupt transition from Prairie grasslands to Rocky Mountains has created exceptional biodiversity in WLNP. The area was designated a UNESCO Biosphere Reserve in 1976. Waterton Lakes National Park is an area with some of the highest precipitation and water yield on the Alberta side of the Rocky Mountains, with maximum monthly precipitation and peak flows in June. Precipitation increases from east to west as one approaches the Rocky Mountains. A large increase in precipitation is projected in both the winter and the spring, which will result in increasing peak flows in the park. In addition, peak flows are expected to increase because of a projected decrease in lag between winter precipitation and melt of the snow pack. This will increase the frequency and severity of spring floods in the park and at the Waterton townsite.

Floods in Waterton Lakes National Park are expected to cause increased erosion damage. Larger sediment transport to the alluvial fans of Blakiston, Sofa, and Stoney Creeks is expected as a result. The Blakiston alluvial fan is one of the largest in the Canadian Rocky Mountains. Erosional features within the park, such as the Sofa Mountain, Mount Crandall, Ruby Ridge Cirques, Red Rock Canyon and the Waterton Valley will likely experience accelerated rates of erosion. The increase in spring run-off is also expected to increase erosion in the Crypt Lake karst system.

Waterton hosts a number of significant aquatic species. The increasing temperatures through the spring, summer and fall are expected to increase stratification of the park's four major lakes. Each has a distinctive aquatic community, which will respond differently to increasing lake levels and warmer temperatures. The ice-free period should also increase as a result of warmer conditions.

Waterton Lakes National Park is characterized by five ecoregions with distinct flora and fauna: wetland, prairie, parkland, montane forest, subalpine forest and alpine. The alpine regions display shorter growing seasons and greater precipitation compared with the prairie. The projected increase in winter precipitation will better protect small plants and mammals in the parkland and montane regions of the park by providing increased insulation against harsh winter temperatures. This snow-pack increase will, however, tend to impede the movement of large animals (e.g., elk), in their wintering habitat on the prairie in the east of the park. The characteristic Chinooks and high winds of southern Alberta typically melt and blow the snow away from the prairie food sources upon which ungulate herds depend in winter. With the significant increase in precipitation during the winter months, the snow cover may remain deeper for longer through the winter. This may result in a migration of ungulate herds onto the relatively snow free plains at lower altitudes to escape the harshness of the Waterton winter. In summer the elk migrate upslope to escape the heat and the flies of the prairie. This migration may become more extensive as the summer temperature increases and precipitation decreases. These conditions will also result in more favourable habitat further upslope for insect pests. The bighorn sheep also migrate downslope in the fall. The increase in winter precipitation may require a longer migration route, in order for the sheep to find sufficient food to survive the winter months. These trends will have implications for landowners near the park and may cause tensions between ranchers and the park.

Both latitudinal and elevational shifts in plant communities can be expected as a result of changes in temperature and precipitation. A temperature increase of between 1 and 6°C will cause vegetation zones to shift upwards by approximately 500 to 600 metres, the equivalent of one vegetation zone in mountainous regions (Stone, 1996). This shift may result in the loss of some alpine species that will be unable to compete with subalpine or montane species invading from lower elevations. Increased forest fire frequency and intensity is expected as a result of decreases in summer precipitation and increases in evapotranspiration rates (Harding and McCullum, 1997). In addition, outbreaks of mountain pine beetle are expected to increase, as higher summer temperatures and a decrease in severe winter cold spells will create more favourable conditions.

Waterton is a waterfowl fly-over route. The wetland complexes provide special habitat for a number of bird species. Increased winter and spring temperatures will probably outweigh the effect of the anticipated increase in winter snowpack and lead to the earlier thaw of wetlands. As a result, spring migrants may arrive earlier.

Waterton Lakes National Park contains a number of archaeological sites. The sites located along the shores of lakes and rivers may need to be protected from flooding and erosion. Increased spring flooding could also affect bridges, culverts, roads and other town infrastructure. Overall, more favourable annual temperatures will increase the summer tourist traffic to the park for both backcountry and front-country use. If the heavier winter snowpack exceeds melting from warmer temperatures, access to high elevation hiking trails may be limited in the early summer. However, the length of the season for summer

recreation activities, such as camping, boating and hiking is expected to increase at the expense of the season for winter recreation. Backcountry use and campfire policies may need to be evaluated given increased forest fire risk. Reduced water supply in the late summer and fall may also require adaptive measures. Pressure for regulation of stream flow within Waterton to supply irrigation water on the plains may also arise.

3.4.7 Yoho National Park

Yoho National Park			
DATE ESTABLISHED	1886		
LOCATION	British Columbia – Park Geocentroid: 51.38°N, 116.51°W		
SIZE	47 km^2		
FEATURES	• Rocky Mountains Natural Region • Takkakaw Falls • Burgess Shale • Kicking Horse Pass/River • The Natural Bridge		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +5.0	SPRING	+1.0 to +10.0
SUMMER	+1.0 to +3.0	SUMMER	-13.0 to +2.0
FALL	+2.0 to +3.0	FALL	-1.0 to +23.0
WINTER	+2.0 to +5.0	WINTER	+2.0 to +24.0

Yoho National Park is part of the UNESCO Four Mountain Parks World Heritage Sites in the Canadian Rocky Mountains. The Kicking Horse River drains Yoho National Park. Flow volumes should increase as a result of climate change. The projected increase in annual temperatures will cause increased melting of high altitude snow pack and glaciers. Despite increased winter snow accumulation, the Wapta Icefield is one of many glaciers in the southern Rocky Mountains projected to retreat rapidly as a result of warmer summer temperatures and increased melt season (Brugmann *et al.*, 1997).

The water levels of all streams, rivers and lakes in Yoho are expected to exceed historic averages in spring and early summer in particular. With the projected increase in summer temperature and decrease in summer precipitation, the stream volumes are expected to decline below historical summer averages in non-glacially fed streams. These hydrologic changes will affect the many waterfalls within Yoho National Park, including Takkakaw Falls and Wapta Falls, by reducing the summer flow over these magnificent features.

With the increase in spring run-off and river and stream velocity that is expected throughout the park, water erosion is expected to increase. In particular, the park's hoodoo formations may experience increased erosion as runoff increases. Significant fossil beds at Mount Stephen and Mount Field may also experience increased erosion with climate

change. The enhanced erosion will increase sediment transport throughout the park, increasing the turbidity of streams and lakes

Increasing winter precipitation will increase the snow depth at higher altitudes. This, combined with increasing temperatures, will result in an increased potential for avalanche activity throughout the park. Climate change impacts related to avalanche activity are discussed in more detail under Glacier and Mount Revelstoke National Parks (3.4.2).

Yoho National Park is characterized by two main ecoregions: the subalpine and the alpine. With climate change, the ecotone between subalpine vegetation and alpine vegetation is expected to shift upward. A mean annual temperature increase of 3°C will result in a 500 to 600 m upward shift of vegetation habitat (Stone, 1996). This will result in a loss of biodiversity for the park, as a number of alpine species will lose their habitat to the species from lower elevations. Further discussion of this trend can be found in the discussion on Banff National Park (Section 3.4.1).

Yoho National Park is home to over 600 species of plants, as well as a variety of fish, mammal and bird species. Mammals on the highest slopes, such as the Rocky Mountain goat, hoary marmot, and pika, are likely to experience a decrease in alpine habitat as a result of the elevational shifts of vegetation belts. However, a greater area of avalanche carved meadows at lower elevation may compensate for this in some animal species. Ungulates at lower altitudes, such as moose and mule deer, will find winter more difficult with increasing snow pack. High elevation wintering ungulates may move into the valleys to avoid deep snow, and as a result, one could expect higher roadway mortality in winter. With the expectation that more of the snow will fall as rain, the crust of the snow will also restrict travel and winter browsing ungulate species.

Both the Trans Canada Highway and the railway pass through Yoho National Park. These features, along with significant backcountry winter use, may be impacted by the potential for increased debris flow and avalanche activity. Thus, the highway and railway may be closed more frequently in winter. The safety of those using the park's travel corridors and the backcountry must be protected due to this potential increase. Yoho and other parks in the region may need to consider enhanced avalanche monitoring, activities, improved warning system, additional search and rescue capabilities, and updated emergency planning.

The length of the season for summer recreation activities such as camping and hiking is expected to increase at the expense of the season for winter recreation activities. Summer park use may increase with warmer and drier conditions. River-based recreation may be affected by higher spring peak flows, making some rapids more difficult than in previous years. Otherwise, backcountry use and campfire policies may need to be reviewed in light of increased forest fire hazard resulting from climate change. Glacier fed streams will rise higher in summer, restricting trail access.

3.5 Pacific Parks

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As in the Atlantic Region, the coastal national parks in the Pacific Region are projected to experience a lesser degree of climatic change than the continental interior. In contrast to the Atlantic coast, isostatic rebound on the Pacific coast will offset sea-level rise to some extent. ENSO and PDO cycles are expected to be exacerbated by climate change. Thus, the ecological impacts associated with extreme events are likely to have a greater role in the Pacific parks. Increased surface water temperatures may have the most important ecological impact on the marine, coastal and riverine ecosystems (including reduced nutrient upwelling, spawning, migrations and the introduction of southerly species) of the region's national parks. The precious coastal cultural artefacts of these parks should be monitored carefully with the likelihood of sea-level rise.

3.5.1 Gwaii Haanas National Park Reserve

Gwaii Haanas National Park Reserve			
DATE ESTABLISHED	1987 (amended 1988)		
LOCATION	British Columbia – Park Geocentroid: 52.25°N, 131.29°W		
SIZE	1,470 km^2		
FEATURES	• Pacific Coast Mountains Natural Region • 138 islands with coastal western hemlock, mountain hemlock and alpine tundra ecoregions • Significant populations of nesting seabirds, peregrine falcon, bald eagle, black bear and black tailed deer (introduced) • 39 species of plants and animals found only in the Queen Charlotte Islands • Rich in Haida culture and archaeology, including numerous totem poles and remnants of villages • Identified climate change as an important ecological stressor in 1997 State of the Parks Report		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	+2.0 to +27.0
SUMMER	+2.0 to +3.0	SUMMER	-17.0 to +3.0
FALL	+2.0 to +3.0	FALL	+2.0 to +13.0
WINTER	+2.0 to +7.0	WINTER	-1.0 to +24.0

The shoreline of Gwaii Haanas is approximately 1700 kilometres in length. The park's terrestrial systems connect and interact in many ways with the marine ecosystem. Any changes in ocean characteristics in response to global warming will therefore have a

strong impact on the terrestrial systems in the park. Sea level rise will have less of an impact on the Pacific Region National Parks because of the nature of the shoreline and offsetting effect of isostatic rebound. Over the past 5000 years, the relative sea-level at Gwaii Haanas has been slowly falling due to isostatic rebound and tectonic action (Fedje, 1993). Thermal expansion of the oceans and melting of glaciers, ice caps and ice sheets will likely raise the absolute global sea-level by 0.5 metres by 2100 (Forbes *et al.*, 1997). Since this rate of sea-level rise is greater than the recent rate of rebound, Gwaii Haanas will experience sea-level rise in the order of a few centimetres per decade (Thomson and Crawford, 1997).

Although the rocky coast of Gwaii Haanas has been classified as having low sensitivity to physical change from sea-level rise (Shaw *et al.*, 1998a), potential impacts can still be identified. A rise in sea-level could threaten sea bird colonies, sea lion haul-outs or low-lying archaeological features, particularly when combined with high storm waves and spring tides. Moreover, sea-level rise could alter the level and salinity of groundwater as well as the balance between fresh and saline estuary habitat in coastal areas (Beckmann *et al.*, 1997). This could be offset by projected increases in runoff (11% - Clair *et al.*, 1998) and fluvial discharge from projected precipitation increases. Changes in salinity and estuarine sediment could also have important effects on shellfish and other estuary dwellers.

The projected 3.5°C increase in sea surface temperatures in the north-east Pacific over then next 50 years could have a major effect on marine ecosystems, particularly cold water fish populations like sockeye and pink salmon (Hinch *et al.*, 1995). This increased sea temperature may lead to an increase in the frequency and distribution of red tide blooms. Warmer water would also support higher populations of southern species such as mackerel and albacore tuna, which prey on and compete heavily with salmon populations (Harper *et al.*, 1994). This impact could be even greater if accompanied by a decrease in primary productivity associated with sub-optimum ocean temperatures. Since salmon form such an integral link in the terrestrial food chain during their migration, other species such as bear and bald eagle are likely to be adversely affected. It is unclear how kelp beds will be impacted by changes in temperature; however they will likely be able to adapt to a slowly rising sea-level.

The anticipated increase in runoff throughout the year could hinder salmon reproduction in existing spawning streams by washing out gravel areas or reducing rearing habitat. Streams that have not historically supported a salmon run may experience adequate flows to open up new areas of rearing and wintering habitat. The impact of earlier peak flows (May instead of June – Clair *et al.*, 1998) for salmon migration and spawning is uncertain. Areas of fluvial and deltaic deposition could also be changed with an increase in base levels of river systems. As sea-level rises, the stream velocity at each stream mouth will decrease, depositing sediment closer to shore. These effects would have implications for all species dependent on coastal and fluvial habitats.

Increases in precipitation could also impact the geomorphology of the park. The steep northern sections of Gwaii Haanas have a high to extreme hazard of mass movement (Westland Resource Group, 1994). An increase in precipitation will result in more frequent and larger magnitude landslides and avalanches (Evans and Clague, 1997).

Changes in winter temperature and precipitation will likely result in an up-slope shift in the snowline and heavier snow-pack in upper elevations. Sites currently on the margin of snow lines would witness a change in precipitation to continued rainfall rather than a period of snow. Warmer spring temperatures would melt the snow-pack more quickly. Implications for altered seasonal hydrology in the park, require further analysis.

Increasing temperatures and precipitation will also impact the wet coastal western hemlock forest. Rising temperatures will likely result in an increase in forest pests and disease (Environment Canada, 1991; Perry, 1991). This could affect the species composition and productivity of temperate rainforests. There may be a gradual species shift toward those favoured by the warmer and wetter conditions (Harding and McCullum, 1997).

Although confined to the higher elevations of the Queen Charlotte Mountain Ranges at the northern edge of the park reserve, the montane spruce and alpine tundra ecoregions could be significantly affected by projected temperature and precipitation changes. The Montane Spruce ecoregion will likely shift in elevation in response to changing snow levels and growing season on the upper boundary of the zone; while coastal western hemlock may gradually replace montane spruce on the lower boundary. Alpine tundra is particularly threatened by conditions favouring the encroachment of species from the montane spruce zone (Hebda, 1997). Depending on the size of remaining alpine habitat, there may be an irreversible species loss on mountain peaks, as viable population sizes are not maintained. It is also possible for conditions to change such that plants previously unable to colonize the islands could now take hold. Due to Gwaii Haanas' isolation from the mainland however, the migration of colonizing species is limited. This could present a situation where the tolerance of existing species is exceeded, yet more southerly species are unable to move into these niches because they are unable to spread across Hecate Strait. If the composition of more southerly coastal forests such as those on Vancouver Island are any indication, the coastal western hemlock forest may face more competition from sitka spruce communities (Hebda, 1997).

Wildlife will also migrate in response to any shifts in plant communities. Changes in predator and prey populations in response to altered climatic conditions could also have a major impact on wildlife. Due to the limited understanding of these relationships, it is difficult to foresee how these shifts will impact species diversity, population size and ecological structure in the park. For example, black tailed deer and black bear may be favoured by an increase in forbs and graminoids as a food source. Conversely, a decrease in meadow size or salmon populations could cancel or outweigh these benefits.

Colonial seabirds have been specifically identified as being threatened by global warming. In addition to their vulnerability to disturbance due to their localized breeding sites, seabirds such as the pelagic cormorant, common murre, Cassin's Auklet, and tufted puffin are under pressure from predators (racoon and rat) introduced to the park (Westland Resource Group, 1994). An increase in sea-level may restrict the size of breeding colonies, further reducing the reproductive success of these species. Other bird species could also be affected by ecological changes, particularly in the food sources of the nearshore marine area.

Gwaii Haanas is rich in Haida cultural resources and archaeological features. Although changes in temperature and precipitation may not directly affect features such as totem poles, burial sites or remains of buildings, secondary effects, such as an increase in sea-level and the severity of winter storms or increased river flooding and erosion, could pose a threat. These factors could also threaten park infrastructure such as buildings, roads and trails.

Changes in visitor use and local activities could be expected as a result of climate change. Extrapolating from this study, increased summer temperature may attract more visitors to Gwaii Haanas during the peak season. In addition, the length of the peak season may be extended. Changes to visitor management programs and additional monitoring of impacts may be necessary.

3.5.2 Kluane National Park Reserve

Kluane National Park Reserve	
DATE ESTABLISHED	1976
LOCATION	Yukon – Park Geocentroid: 60.66°N, 140.17°W
SIZE	22,000 km^2
FEATURES	• North Coast Mountains Natural Region • UNESCO World Heritage Site • Protects the high peaks and icefields of the St. Elias Mountains. • Meltwaters from valley glaciers form sediment-laden rivers flowing out of the mountains. • Alpine, subalpine and montane ecoregions support a wide variety of plants and animals including Dall's sheep, grizzly bear, mountain goat and moose

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	+4.0 to +11.0
SUMMER	+3.0 to +6.0	SUMMER	0.0 to +22.0
FALL	+2.0 to +4.0	FALL	+2.0 to +23.0
WINTER	+2.0 to +4.0	WINTER	-1.0 to +25.0

Kluane National Park Reserve (KNPR) is an area of high mountain peaks shrouded in ice and snow and bordered by a fringe of boreal forest on its eastern edge. The St. Elias

Mountains, Canada's highest peaks, are covered with some of the largest icefields and glaciers in the country. In contrast to the lower elevation glaciers in southern British Columbia, glaciers in the southern Yukon have been advancing. This trend is projected to continue despite higher year round temperatures. Winter snowfall is projected to increase and accumulation zones are high enough for the continued advance of glaciers (Brugman *et al.*, 1997). Furthermore, the reflective properties of an increased snow-pack may further offset melting at the terminus by reducing melting at higher elevations (Brugman *et al.*, 1997).

Some glaciers advance steadily, but some surge unevenly, which is not well understood. The ice advances quickly for a short period then remains quiescent for a number of years. The surge phase is often accompanied by the release of large volumes of turbid meltwater (Hambrey, 1994). The Steele glacier in the north end of Kluane, for instance, surged 11km in four months in 1967. Another catastrophic event that has occurred as recently as the early twentieth century in Kluane is known as a jokulhlaup. In the nineteenth and perhaps early twentieth centuries, the Lowell Glacier blocked the Alsek River, forming a large lake behind the ice (Evans and Clague, 1997). When the ice wall failed due to glacial retreat or floating, the water was released in one surge. Lake Alsek formed and emptied many times over this period. This situation may return to Kluane if the Lowell Glacier advances back into the Alsek Valley and should be reflected in long-term park planning.

Glacial runoff is more strongly influenced by temperature than precipitation (Hambrey, 1994). Projected summer temperature increases of 3 to 6°C in the KNPR area will likely result in increased discharge of glacier-fed rivers such as the Donjek, Duke, Slims, Alsek, Kaskawulsh and Dezadeash. Discharge will continue to rise over time as more precipitation falls on the accumulation zones and more melting occurs with summer higher temperatures. The volume of peak flows in June will be higher and likely shift earlier in the season by a few weeks (Coulson, 1997).

Higher glaciofluvial discharge will increase sediment transportation. Flooding, erosion and deposition of sand and gravel along valleys could alter the stream morphology and vegetation communities along the floodplains. Deltas, such as that at the mouth of the Slims River, will likely increase in size with increased sediment transport. Water turbidity will likely increase overall, despite the diluting effect of higher rainfall in the summer.

It is foreseeable that the increase in glacial surface area and a larger gradient in air temperatures would result in stronger glacial winds as a larger volume of cooled air sinks down into the valleys. As a result, there may be a change in local wind patterns and sediment supply, shifting existing dune structures in the Slims, Donjek and Alsek valleys and expanding these complexes into surrounding vegetation.

Warmer temperatures may reduce the area and depth of mountain permafrost. This has been linked to major rock avalanches and debris flows in European mountains (Evans and Clague, 1997). Change in the balance of freezing and thawing and increased precipitation could also alter solifluction, frost heave processes and rock glaciers. Projected increases

in snow-pack and rainfall could also lead to an increase in the magnitude and frequency of landslides, debris flows, and avalanches in the park. These conditions should be included in a regular monitoring program for front-country areas in particular.

Water bodies such as Kathleen, Bates and Mush Lakes would experience earlier ice break-up and later freeze-over. Water temperature will increase during the summer months and water bodies will experience increased turbidity. It is uncertain if these changes would have a negative impact on the fish species inhabiting these waters. The levels of these lakes are likely to rise with the increase in glacial discharge and increased precipitation. This will decrease the size of Bates Lake Island, a nesting colony for arctic terns, mew gulls and herring gulls. The nesting trumpeter swan population at the confluence of Alder and Fraser Creeks could also be displaced by increased water levels.

The rise in precipitation and water levels could also result in the increase of groundwater supplies and a higher water table in many locations. This may increase the habitat for moose in areas of wet montane vegetation. A longer growing season will result in an increase in soil development and primary plant productivity. The latter will increase the food supplies for the fauna of the park, including grizzly bear, Dall's sheep, and mountain goats. Unfortunately, the winter food supply may become more scarce since increased snowfall and ice layers from winter rain events would make foraging more difficult. An increased snow pack would also restrict the mobility of ungulate populations, adding to the winter stress. It is not known if these adverse impacts will exceed the benefits brought on by milder temperatures and shorter winters for ungulate populations (Harding and McCullum, 1997).

Projected climate change would increase the instability of ecological communities presently in KNPR. It is likely that more southerly species will migrate into the park, as conditions become milder. Invasive species with aggressive colonization strategies would be favoured in a disturbed ecological state (Harding and McCullum, 1997). Changes in elevational distributions are also likely, with montane, subalpine and alpine communities shifting upslope. It is uncertain whether the treeline will move upslope or the increased snow-pack will retard tree establishment (Krannitz and Kesting, 1997). If the treeline expands, habitat for subalpine species may be reduced, resulting in extirpation of some species. The findings of Lenihan and Neilson's (1995) study in the KNPR area are illustrative of this uncertainty.

Insect infestations in the KNPR area occur in the range of one to several decades (Slocombe, 1999). Forest insect infestations and disease cycles are likely to increase with milder conditions (Environment Canada, 1991; Perry, 1991). Forest fire intervals are presently in the order of 200-300 years in KNPR (Hawkes, 1983). Despite a projected increase in summer precipitation, the longer warm season, increased temperatures and greater fuel accumulation from pest and disease mortality would likely result in more frequent forest fires. Increased disturbance from insect, disease and fire would decrease forest stability and later species composition in the park.

Warmer temperatures will likely result in increased park visitation. This may result in the increase in grizzly bear-human interactions or disturbance of other wildlife species. Summer and shoulder season activities, particularly in the backcountry, could change as a result of increased snow-pack, river flow, or glacial features. The season for rafting on the Alsek River could likely increase in length. Increases in precipitation and glacial runoff could significantly increase water levels, increasing difficulty levels of many rapids. Park infrastructure such as trails, parking lots, bridges, buildings and interpretative facilities could be at a higher exposure to natural hazards such as flooding or landslides. Erosion, flooding or deposition could threaten archaeological resources, such as the settlement at the mouth of the Donjek River. Avalanches may also become more of a hazard in winter and spring. Winter recreation may increase if temperatures are warm enough for activities such as cross-country skiing and snowshoeing.

3.5.3 Pacific Rim National Park Reserve

Pacific Rim National Park Reserve	
DATE ESTABLISHED	1970 (amended 1987)
LOCATION	British Columbia – Park Geocentroid: 49.84°N, 125.06°W
SIZE	500 km^2
FEATURES	• Pacific Coast Mountains Natural Region • Three sections of coastline along western Vancouver Island (Long Beach Unit, Broken Islands Group and West Coast Trail Unit) with sitka spruce and coastal western hemlock ecoregions • Significant populations of nesting seabirds, sea lions, bald eagle, black bear • Heavily used beach, trail, and campsite infrastructure • Identified climate change as an important ecological stressor in 1997 State of the Parks Report

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+2.0 to +4.0	SPRING	-9.0 to +3.0
SUMMER	+2.0 to +3.0	SUMMER	-32.0 to 0.0
FALL	+2.0 to +3.0	FALL	-7.0 to +32.0
WINTER	+2.0 to +4.0	WINTER	+3.0 to +34.0

Pacific Rim National Park Reserve protects a wide variety of marine habitats including exposed rocky shorelines, wide sandy beaches, tidal mud flats and estuaries and numerous small islands. The most significant impact of climate change in Pacific Rim is likely to be increased sea-level. The IPCC projected thermal expansion of the oceans and melting of glaciers, ice caps and ice sheets will raise the absolute global sea-level by 0.5 metres by 2100 (Forbes *et al.*, 1997). When coupled with tectonic uplift and isostatic rebound, the level is anticipated to rise 0.2 metres on the West Coast of Vancouver Island (Thomson and Crawford, 1997).[10]

The shoreline of Pacific Rim National Park is moderately sensitive to physical impacts from sea-level rise (Shaw *et al.*, 1998a). Even gradual sea-level rise could cause changes to tidal mudflats, estuaries, beach processes, and sea bird colonies. It could also exacerbate the erosion problems at popular beach recreation sites such as Comber's Beach, North Long Beach and the terrace scarp at Florencia Bay. The tidal mudflats in Grice Bay may be reduced in size if the rate of water level rise exceeds the rate of buildup by sedimentation. Colonial seabirds such as the pelagic cormorant, Brandt's cormorant, common murre, Cassin's auklet, and tufted puffin could be threatened by a resultant reduction in suitable nesting sites.

The changes in sea-level and storm energy due to increased atmospheric instability may result in the shifting of the beach-dune complexes along the shore of Long Beach, particularly close to Wickanninish. The existing system will likely become increasingly unstable and sand could migrate further inland. Although there has been little analysis of the sensitivity of Pacific parks to ENSO cycles, the most intense erosion events have occurred during El Nino events. Climate change is expected to exacerbate ENSO conditions, thus extreme events are likely to play an increasingly important ecological role in the Pacific national parks.

The projected 3.5°C increase in Northeast Pacific sea surface temperatures by 2050 could have a major effect on marine ecosystems, particularly cold water fish populations (Hinch *et al.*, 1995). This increased sea temperature may lead to an increase in the frequency and distribution of red tide blooms. Warmer water may reduce the frequency and duration of coastal fog. Warmer water would also support higher populations of southern species such as mackerel and albacore tuna, which prey on and compete heavily with salmon populations (Harper et al., 1994). This impact could be even greater if accompanied by a decrease in primary productivity associated with a decrease in oxygen and nutrient upwelling. It is unclear how kelp beds will be impacted by changes in temperature, although they will likely be able to adapt to a slow rise in sea-level.

Areas of fluvial and deltaic deposition could also be changed with an increase in stream energy associated with increased precipitation. Increased erosion of upstream sections and increased deposition in downstream areas can be anticipated. These effects would impact many species dependent on coastal and fluvial habitats at some stage of their life cycles. Salmon may also be impacted by altered river water levels. Changes in water levels could hamper upstream migration, wash out areas of spawning gravel or reduce rearing habitat. It is also possible that the increased stream flow might open up new areas for salmon spawning in some locations. Increased temperatures in streams and Kennedy Lake could result in high levels of mortality among salmon (Levy, 1994). Water clarity could be reduced with an increase in upland erosion and landslides during heavier winter precipitation, particularly when combined with past logging activities on steep slopes.

Competitive relationships and regeneration patterns in the park will be altered by changing climate. Since both summer air temperatures and sea surface temperatures will rise, the effect of global warming on coastal advection fog is unclear. Increased winter

rainfall would probably have only a minor impact on the wet coastal western hemlock and sitka spruce forest systems, since these areas are already saturated much of this time. These forest areas will be more affected by projected decreases in summer precipitation and increased summer temperatures. The sitka spruce forest may extend further inland as this community is more tolerant of mesic conditions. There may also be a shift to Douglas fir communities as conditions shift to drier, warmer summers (Hebda, 1997). These trees live for hundreds of years and consequently, the effects of species shifts will likely be visible for centuries.

The decrease in summer precipitation would also result in decreased water levels in the ancient bog forest complexes within the park. The lack of water may cause some bog areas to be taken over by species more tolerant of dry summer conditions. This may result in changes to peat accumulation rates and bog surface pH. Changes in humidity would probably affect the species composition and productivity of temperate rainforests, especially that of epiphytic mosses and lichens. Increased winter storms may be expected to spread salt spray further inland, which again favours spruce over hemlock. The coastal spruce zone would thus widen.

Decreased summer precipitation and increased evaporation caused by higher temperatures could result in shortages in groundwater supply in summer months. Since the aquifer is likely to be fully recharged during the winter, a precipitation increase in this season will not counteract the drop in summer rainfall. In addition, the rise in sea-level and salt water pressure could make some groundwater sources too saline for drinking (Beckmann *et al.*, 1997).

Rising temperatures will likely result in an increase in forest pests and disease (Environment Canada, 1991; Perry, 1991). The decrease in summer precipitation may also result in an increased forest fire hazard. Historically uncommon in the coastal western hemlock forests which make up Pacific Rim, natural or human-caused fires may increase in frequency and size with drier conditions (Hebda, 1997).

Finally, changes in visitor use and local activities can be expected as a result of climate change. An increase in summer temperatures coupled with a decrease in precipitation could lead to a higher number of visitors to Pacific Rim during the peak and shoulder seasons. Increased summer visitors would intensify pressure for urban development, especially in Tofino and Ucluelet, and potentially increase park revenue from camping and parking fees. Changes in visitation pattern would be particularly pronounced if the gray whale migration shifted earlier in the season with warmer ocean temperatures. It is uncertain how gray whale populations will be impacted by changes in ocean temperature or food supply in their wintering grounds off of the coast of Mexico. Visitor use could also be impacted in the Broken Islands Group and West Coast Trail Unit, where an increase in sea-level could result in changes to campsites and trail locations. Sea-level rise could also threaten any low-lying archaeological or cultural features, such as Cloo-ose or Nuu-chah-nulth heritage sites. Increased landslide activity resulting from heavier winter precipitation would also impact park infrastructure and cultural sites, particularly along the West Coast Trail Unit.

3.6 Arctic Parks

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Environmental conditions (temperature, light, growing season) are close to the limits for life in Arctic ecosystems (Danks, 1992). Considering the magnitude of projected climate change in Arctic Canada, ecosystems in this region are likely to be the most sensitive to global climate change. Projected temperature increases would extend the growing season and in southern Arctic parks allow the expansion of forested areas. The tree line is projected to more northward by 200 to 300 kilometres in some areas. Thawing of permafrost areas in some parks (a northern shift of approximately 500 kilometres has been projected) will have implications for park landscapes (e.g., increase in thermokarst ponds and altered hydrology). Statistically significant increases in territorial rivers that cannot be accounted for by precipitation patterns suggest accelerated permafrost melting, leading to the dewatering of the landscape may be underway (Whitfield, 2000). Increased temperatures will also increase the severity and length of the insect season, with attendant increases in harassment of caribou and species.

The magnitude of projected seasonal temperature increase in the region is partially the result of diminished reflective capacity from reduced periods of snow and ice cover. The reduction of sea ice has important implications for several mammal populations (e.g., ringed seals and polar bears). Sea-level rise will have varied effects on Arctic region parks. Isostatic rebound in the Quttinirpaaq National Park area will largely negate projected sea-level rise, while subsidence in the Auyuittuq and Ivvavik National Parks will exacerbate sea-level rise (with a net 0.5 to 1 metre rise in sea-level over the next 100 years).

Altered caribou migration patterns and the potential loss of rich archaeological sites (from increased spring flooding and erosion and increased decomposition) have important cultural implications for this region.

3.6.1 *Aulavik National Park*

Aulavik National Park			
DATE ESTABLISHED	1992		
LOCATION	Nunavut Territory – Park Geocentroid: 73.59°N, 119.74°W		
SIZE	12,200 km^2		
FEATURES	• Western Arctic Lowlands Natural Region • Deeply cut river canyons; rolling tundra barrenlands with wetlands along rivers • One of highest muskoxen concentrations in the world • Calving grounds for Peary caribou • Moulting grounds for black brants and snow geese • Archaeological sites dating back 3,400 years		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+4.0 to +6.0	SPRING	-13.0 to +17.0
SUMMER	+1.0 to +5.0	SUMMER	-8.0 to +44.0
FALL	+4.0 to +8.0	FALL	+9.0 to +23.0
WINTER	+5.0 to +11.0	WINTER	-18.0 to +37.0

GCMs project warmer year-round temperatures in Aulavik National Park (ANP), particularly during the fall, winter, and spring months. Annual increases in precipitation are also expected, although the magnitude of seasonal changes is still uncertain. In general, increased precipitation will lead to more wet snow accumulation, increased spring runoff volumes, wetter soils, and faster river currents. Warmer temperatures may lead to earlier spring melts, earlier soil thawing, longer (sea and lake) open water seasons, decreased ice thickness, sea-level rises, increased frequency of freezing rain, and increased active soil layer depth in permafrost areas. These changes in climate, hydrology, and geomorphology will undoubtedly affect vegetation and cultural features of the park. Shifts in vegetation distribution and availability will then lead to changes in the status of wildlife populations of ANP.

A relative sea-level rise of 0.6 to 0.9m per century can be expected in the region, since it experiences a submergence rate of 0.1 to 0.4m per century (Hill, 1993) and global sea-levels are expected to rise by 0.5m per century with global warming. This combined effect puts the park's coastal areas at added risk to increased shoreline erosion and saltwater intrusion (Maxwell, 1997). The shoreline of the park is moderately sensitive to physical impacts from sea-level rise, with the most sensitive features being beaches in front of bluffs of unconsolidated sediment, deltas and estuaries (Shaw *et al.*, 1998a).

The open water season in the Beaufort Sea is projected to increase by up to 90 days, with a decreased sea ice thickness of 50 to 75% (Maxwell, 1997). Observations at Holman on Victoria Island indicate ice break-up and freeze-up have occurred 2 to 3 weeks earlier and later respectively over the past 5 to 10 years (Inuktalik, 2000). Multi-year ice is becoming rare at Sachs Harbour on Banks Island, with detrimental impacts for seal pupping (Snow,

2000). Increased ice-free season may lead to increased wave development and a higher frequency of coastal erosion and cliff destabilization along the shores of ANP. Other areas will see coastal deposition of these eroded materials.

Projected climate change will affect the hydrology of ANP. Currently, erosion by swollen spring river flows is minimal because a protective layer of snow remains on the riverbanks and the ground is still frozen (Zoltai *et al.*, 1980). Warmer winter and spring temperatures may however, lead to unfrozen ground and less protective snow cover during peak spring melt periods (expected in June rather than July – Clair *et al.*, 1998), thereby causing increased erosion and slumping of bank material. Bank destabilization could lead to increased suspended load and sediment deposition in rivers.

The Thomsen River basin is one of the most northerly examples of a multi-species freshwater fish community (Zoltai *et al.*, 1980). Species assemblages may change if water temperature increase (Rouse *et al.*, 1997). Arctic char spawning grounds in ANP may be at risk from increased sediment loads and faster currents in rivers.

Due to its northerly location, ANP will still remain in the continuous permafrost zone (Maxwell, 1997). The active layer depth is expected to increase and some ground ice wedges could melt, leading to increased thermokarst topography and soil slumping in the park (Maxwell, 1997). Large new areas of thermokarst have developed inland on Victoria Island (Inuktalik, 2000). It is unlikely that the active layer will melt enough to significantly increase subsurface water storage, therefore increased downslope movement of soil and increased overland flow would be the likely result of an increased precipitation regime. The warmer, wetter climate may also lead to increased development of peat landforms. Conversely, historical evidence suggests that pingos only began forming when the climate became drier and colder (Zoltai *et al.*, 1980). Pingos may only persist until wind and water erosion eliminates them from the park landscape.

With increased moisture availability due to the melting of permafrost and increased precipitation, the barren lands of ANP may become increasingly populated by tundra plant species (Maxwell, 1997). In addition, low lying areas might become even wetter, thereby increasing the total amount of wet sedge habitat in the park. Increased total vegetation under a warmer and wetter climate could lead to the reformation of peatlands and increased evapotranspiration rates in short term (Maxwell, 1997). Moreover, an increased active layer implies more efficient nitrogen circulation, which may increase biological productivity.

Increased abundance of meadow species for summer forage will be positive for the muskox population of ANP. Conversely, mild winters with heavy snowfall and increased incidence of freezing rain would reduce access to winter forage, increase nutritional stress, and limit mobility of ungulate populations (Gunn, 1995). These conditions could lead to decreased calf production and survival, and may eventually lead to the extirpation

of muskoxen from Banks Island. The potential shifts in vegetation may have a similar detrimental impact on the caribou population of ANP. The potential increase in severity and length of the insect season would also further stress these species (Russell, 1993). As Banks Island is rather flat, the opportunities for caribou and muskoxen to summer at higher altitude to avoid flies are limited. Decreased winter sea ice formation might limit inter-island migration and genetic exchange among the caribou herds of the arctic islands, which will inevitably result in a depleted genetic stock of the Peary caribou of Banks Island (Maxwell, 1997; Zoltai *et al.*, 1980).

The importance of ANP as moulting grounds for black brants and snow geese will not likely be affected in the short term by potential increases in wetland habitat. Shorebirds and waterfowl visiting the area may be affected by decreased availability of low-lying coastal habitat if rising sea-level leads to saltwater inundation. New areas of coastal marsh may form as others are flooded, mitigating some of these impacts on coastal birds. Cliff nesting birds may also be affected by cliff destabilization due to increased wave action (Maxwell, 1997).

Lemmings are keystone species in ANP because many birds of prey and other predators rely on them (Zoltai *et al.*, 1980). Kerr and Packer (1998) project severe range reductions for lemmings in the face of increased warming, which will have substantial consequences for the arctic ecology.

Recreation and tourism opportunities in ANP may be affected. Overland hiking may become more difficult as the ground moisture increases and wildlife viewing opportunities will diminish if the aforementioned species losses occur. However, increased river volumes may lead to greater opportunity for river use since current levels are often too low for late-summer river use (Zoltai *et al.*, 1980). Wind and visibility conditions may hamper improved hydrologic conditions (Maxwell, 1997). Terrain destabilization through decreased permafrost, and increased wind and water action may also impact park infrastructure and sites of historic significance.

3.6.2 *Auyuittuq National Park*

Auyuittuq National Park			
DATE ESTABLISHED	1976		
LOCATION	Nunavut Territory – Park Geocentroid: 67.59°N, 66.60°W		
SIZE	19,700 km^2		
FEATURES	• Northern Davis Natural Region • 6000 km^2 Penny Ice Cap; mountains and glaciers • Permafrost terrain • 300 species of Arctic tundra vegetation • Polar bears, barren-ground caribou, marine mammals • Native community and subsistence hunting • Archaeological sites of historic significance		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+3.0 to +4.0	SPRING	-7.0 to +29.0
SUMMER	+1.0 to +3.0	SUMMER	-4.0 to +28.0
FALL	+2.0 to +4.0	FALL	+4.0 to +29.0
WINTER	+3.0 to +10.0	WINTER	-4.0 to +21.0

Global warming is expected to result in warmer year-round temperatures and increased precipitation in Auyuittuq National Park (ANP), with implications for park glaciers, coastal areas, hydrology, geomorphology, flora, fauna, and cultural resources. Winter and spring warming of between 3 and 10°C will lead to earlier spring melts, later fall ice formation, longer ice-free seasons on lakes and rivers, and on the sea, as well as changes in the continuous permafrost layer. Increased winter precipitation will lead to more wet snow and ice accumulation, and increased spring runoff volume. Increases in summer precipitation may lead to more cloudy conditions, with low solar radiation. Increased iceberg calving and warmer summer air conditions may induce more coastal fog, and increased melting may lower salinity in the surface waters of fjords.

The eastern coast of Baffin Island is currently submerging at a rate of 0.5m per century (Maxwell, 1997). This submergence, coupled with the anticipated 0.5m per century rise in global sea-levels would lead to a net 1m rise in sea-level over the next 100 years. This would lead to substantial changes in the tidewater glaciers of Baffin Island as well as changes in the intertidal community (Maxwell, 1997). Overall, the predominately rocky shoreline is of low sensitivity to impacts from sea-level rise (Shaw *et al.*, 1998a).

Water levels of the rivers and lakes in ANP may also increase due to the increased volume of spring melt, summer glacier melt, and summer precipitation. Spring peak flows will also occur slightly earlier in the year (June instead of July – Clair *et al.*, 1998). These increased flows may lead to increased flooding and erosion, as well as changes in suspended load and sediment depositional patterns, which may impact fish habitat in lakes, rivers and nearshore marine areas.

With increased fall, winter, and spring temperatures the ice-free season on lakes and rivers in the ANP region may start 30-35 days earlier (Maxwell and Barrie, 1989). Arctic seas are similarly expected to have extended open water seasons, thinner sea ice cover, earlier spring ice breakup, and later fall sea ice formation (Hansell *et al.*, 1998). This will have substantial impacts on sea mammals. For example, ringed seals will be forced further north if their habitat requirements can no longer be met. The northward movement of sea mammals and the reduction of fast ice and floes will have tremendous implications for the polar bear populations of ANP. In particular, changes in the extent and type of ice cover will reduce their ability to access prey (Tynan and DeMaster, 1997). Consequently, polar bears may be forced to move north or to stay inland longer, which would increase nutritional stress levels and lower reproductive success (Messier *et al.*, 1994).

According to Maxwell (1997), glaciers in arctic regions are expected to change little in overall mass balance. In ANPR, there may be increases in summer melting at low altitudes, but this will be counterbalanced by increased deposition of snow and/or ice during the winter months in accumulation zones. The region may therefore undergo a period of neoglaciation if increased winter precipitation prevails over increased summer temperature (Dowdeswell *et al.*, 1997; Svoboda, 1994).

Periglacial processes will probably be affected by the anticipated changes in ANP. Permafrost boundaries may move northwards by as much as 500km (Rouse *et al.*, 1997), which would lead to a shift from continuous to discontinuous underlying permafrost in ANP (Maxwell, 1997; Kane, 1997; Hon, 1995). This could result in increased slope movements such as mudflows, slumping, and solifluction. Increased temperatures and precipitation in ANPR may lead to geomorphological changes, including increased occurrences of land forms associated with frost weathering (e.g., weathering pits), and changes in patterned ground associated with permafrost (e.g., stone sorting, polygonal ice wedges). Furthermore, the occurrence of rockfalls, avalanches, and landslides arising from frost shattering and spring thaw (McKenna-Newton, 1985) are expected to increase (Environment Canada, 1989). These changes would be more pronounced at low altitude.

Vegetation will also be affected by these geomorphological changes (Hansell *et al.*, 1998). In many arctic regions there is a risk of invasion of more southerly species (Maxwell and Barrie, 1989), however the isolation of ANP may limit the impact to area ecosystems. Subtle shifts in dominant plant species may be observed due to changes in water and soil nutrient levels (Press *et al.*, 1998). Increased vigour, productivity, and reproductive successes of tundra plants may be minimal in ANP due to relatively minor summer warming.

Caribou, an important feature of ANP, are a significant food source for local Inuit. Caribou herds will likely be most affected by increased temperatures and precipitation during the winter months. Increased snow depth and/or the presence of ice layers in the snow will lead to increased energy expenditure in foraging, which may result in lower nutritional levels and lower reproductive success. In addition, caribou migration patterns

may be altered due to changes in spring runoff levels and timing of the melt (Brotton and Wall, 1997). Insect harassment during summer months may increase, which could combine with the impacts of poor winter foraging as a cumulative negative effect on the health of ANP's caribou herds (Russell, 1993). The impact of increased fly harassment may be mitigated somewhat if occasional snow banks remain at lower elevations throughout the summer months to provide areas for insect avoidance (see also Aulavik NP - Section 3.6.1).

Cultural aspects of ANP will also be impacted by changes in hydrology, geomorphology, and wildlife distributions. Sites of archaeological significance, which occur near lakes, rivers, and the coast, may be eroded due to increased spring runoff and coastal flooding. Tourism in the park might increase moderately given a longer tourist season (Kochmer and Johnson, 1995). There may also be problems with park and neighbouring infrastructure, such as increased slumping in buildings and destabilization of roads, airstrips and trails due to loss of permafrost and increased runoff and erosion (Etkin et al., 1998; Hansell *et al.*, 1998). More significantly, local people will be affected by changes in caribou migration paths and times (Brotton and Wall, 1997), and movements of sea mammals due to changes in sea ice conditions. This will undoubtedly have an impact on lifestyle and cultural traditions in the area.

3.6.3 Ivvavik National Park

Ivvavik National Park	
DATE ESTABLISHED	1984
LOCATION	Yukon Territory – Park Geocentroid: 69.09°N, 139.46°W
SIZE	10,170 km^2
FEATURES	• Northern Yukon and Mackenzie Delta Natural Regions • Major rivers forming deltas and coastal barrier beaches • Ancient unglaciated landforms • Porcupine caribou herd calving and summering grounds • Most northern population of Dall's sheep in the Yukon • Arctic char spawning and overwintering grounds • Snow geese staging area • Rich archaeology from Pleistocene, and unique historic sites

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+4.0 to +6.0	SPRING	-4.0 to +14.0
SUMMER	+2.0 to +5.0	SUMMER	+12.0 to +28.0
FALL	+3.0 to +5.0	FALL	+4.0 to +13.0
WINTER	+4.0 to +6.0	WINTER	-3.0 to +33.0

All GCMs project increased temperature and precipitation in Ivvavik National Park (INP). Increased temperatures will likely lead to more open water, longer open water

season, decreased winter ice thickness, and decreased permafrost. Changes in precipitation will likely lead to increased snow accumulation, higher spring runoff volumes, more coastal fog and cloudiness, and increased soil moisture. The implications of these changes on park shorelines, landforms, vegetation, wildlife, and cultural heritage are discussed. See also the discussion for Vuntut National Park (Section 3.6.6) for other regional implications of climate change.

The anticipated 0.5m per century rise in global sea-level will be amplified by submergence of 0.1 to 0.4m per century in the Beaufort Sea area. The coastal shorelines of INP were rated as moderately to highly sensitive to physical impacts from rising sea-levels (Shaw *et al.*, 1998a). Sea-level rise, combined with increased wave action may cause the alluvial fans and associated dune and wetland systems of the Firth, Malcolm and Backhouse Rivers to erode and be redeposited further inland. Wetland areas may therefore diminish given their sensitive location between the sea and river flood embankments (Beckmann *et al.*, 1997). As coastal erosion increases, more ice-rich tills will slump into the sea and be swept away and redeposited as spits and barrier beaches. This might have a positive impact on the lagoon habitats found offshore to INP.

The open-water season of the Beaufort Sea is expected to increase by up to 90 days, while the extent of open water may increase from its present maximum of 150 to 200 km to about 500 to 800 km (Maxwell, 1997). A decrease in winter ice thickness of 35% (currently averaging 2.5m) is also projected (Maxwell, 1997). These changes would lead to more intense wave action, causing increased shoreline erosion and more frequent storm surges (Maxwell, 1997; Beckmann *et al.*, 1997). Riverbanks would experience increased erosion as a result of earlier ice break-up and peak spring runoff (June instead of July – Clair *et al.*, 1998). This, in turn, will lead to more bank erosion, landslides and increased stream turbidity.

Changes in the underlying permafrost would likely have an impact on the characteristic patterned ground associated with ground ice and permafrost. Under a warmer, wetter climate regime tundra ponds associated with low-centred ice wedge polygons may become increasingly colonized by sedges and mosses. This might give rise to more peatlands and increased formation of peat mounds. In addition, there may be an increase in thermokarst ponds and associated topography as ice-rich soils thaw with increased summer temperatures.

Since INP is located at a transition from low arctic tundra to subarctic woodlands, warmer summer temperatures and increased moisture availability may cause an expansion in forested area (Maxwell, 1997; Landhausser and Wein, 1993). Spruce-willow woodlands may have an opportunity to expand given the more favourable climatic conditions, while the higher elevation dwarf shrublands of the British Mountains may undergo some range contraction as they are forced to higher elevations. Windswept sites and their associated vegetation (dwarf willows, herb mats, cushion plants, and lichen) will be less affected because only low-lying species adapted to harsh winds would be able to colonize the area.

Sedge-moss vegetation of the arctic coastal plain may increase in the short term as the overall productivity of ice-wedge polygons increases. These vegetation types might eventually decrease, as competition from boreal species increases.

Park wildlife will be affected by these vegetation changes. For instance, much of the western Canadian population of snow geese and sea ducks that use coastal areas as staging grounds will be forced elsewhere if climate change results in reduced coastal habitat and/or increased shoreline erosion. Increased pond formation may favour aquatic insects, waterfowl and the food chains that they support. In addition, the arctic coastal plains are important as calving grounds for the Porcupine caribou herd. Calving success can be affected by changes in vegetation, variable snow conditions (both on calving and wintering grounds), and increased insect harassment (Brotton and Wall, 1997; Hansell *et al.*, 1998). Caribou herds will be forced to seek higher ground during the calving season if insect harassment increases substantially. Herd numbers could also suffer if predators, such as grizzly bears, increase in abundance with a more favourable climate. The caribou herd is essential for the continuation of traditional lifestyles of the people from surrounding communities (Parks Canada, 1993).

The overall diversity of small mammals and birds is high in INP due to the presence of arctic, treeline, and boreal species (Parks Canada, 1993). Diversity may decrease if the boreal and treeline species out-compete arctic species as climate becomes warmer and wetter.

Many streams in INP freeze to the bottom during winter and undergo periods of intense riverbed scouring by ice in the spring, resulting in high annual disturbance and limited biological productivity (Parks Canada, 1993). As air temperatures warm, river ice thickness may be reduced, which could result in increased species diversity. Rivers and streams may also be able to support larger overwintering fish populations. Significant fish habitats, such as anadromous char breeding areas along the Firth River may be negatively affected as water quality decreases with increased erosion and sediment load. Bryan *et al.* (1973:2) indicated, "rather small increases in sedimentation markedly decrease the number of fish in an area and also decrease their food supply and growth rate."

One cultural loss the park might expect as a result of sea-level rise is some of the coastal historical sites associated with coastal whaling and seal hunting. Similarly, evidence of early human culture alongside rivers, especially archaeological sites bordering the Firth River, may be lost as wind and water erosion increases. The potential for tourism during the summer would increase, as long as increased insect harassment does not negate the benefits of warmer temperatures. Whitewater rafting along the Firth River may benefit from a longer season. The anticipated 12 to 28% increase in summer precipitation may also result in higher levels of difficulty for many rapids.

3.6.4 *Quttinirpaaq (formerly Ellesmere Island)*

Quttinirpaaq National Park			
DATE ESTABLISHED	1988		
LOCATION	Nunavut Territory – Park Geocentroid: 82.08°N, 71.05°W		
SIZE	37,775 km²		
FEATURES	• Eastern High Arctic Glacier Natural Region • Ice cap, glaciers, shore fast ice shelves • Thermal oases of high biological productivity amidst a polar desert • Peary caribou; muskoxen; arctic wolves, foxes and hares • Remains from ancient Inuit cultures, research camps, and exploration		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+4.0 to +5.0	SPRING	-14.0 to 0.0
SUMMER	+1.0 to +7.0	SUMMER	-4.0 to +20.0
FALL	+4.0 to +8.0	FALL	+10.0 to +23.0
WINTER	+5.0 to +7.0	WINTER	+2.0 to +23.0

Quttinirpaaq National Park Reserve (QNPR) lies at Canada's northernmost extremity. Despite the extreme conditions, the tundra is able to support communities of small and large grazers (e.g., Arctic hare, lemmings, muskoxen, and caribou). Temperatures at QNP are expected to increase between 1 and 8°C, depending on the season. This should lead to decreased ice cover and ice thickness, less meltwater refreezing on glaciers, and increased melting of the active permafrost layer. Precipitation increases of between 2 and 23% are also expected during fall and winter months. This will likely lead to increased snow accumulation, more freezing rain in early and late winter, increased coastal fogginess and cloudiness, increased ground moisture, and higher spring melt stream flows. Spring precipitation is expected to decrease by as much as 14%, which might lessen the impacts of increased spring runoff. Potential implications of increased temperature and precipitation on park hydrology, glaciers and ice caps, permafrost, vegetation, wildlife, archaeology, and tourism are outlined.

Global sea-levels are expected to rise 0.5m per century. The coastal zone of QNP will not likely be affected by these changes because the park is currently experiencing isostatic rebound and tectonic uplift in the order of 5m per century (Parks Canada, 1994). The rocky shoreline of QNP was therefore rated as low sensitivity to physical impacts from sea-level rise (Shaw *et al.*, 1998a).

There is likely to be substantially less sea ice in the Arctic Ocean due to increased temperatures and associated changes in atmospheric and oceanic circulation (Maxwell, 1997). This could have several implications for the northern coast of QNP. First, the longer open water season on the Arctic Ocean may lead to changes in oceanic and atmospheric circulation patterns. This could lead to increased occurrence of year-round open water bodies, or polynyas, along the shores of QNP, with attendant increased

biological productivity of the area. In addition, the longer open water season may lead to more severe wave development (Maxwell, 1997). Increased wave action, in combination with warmer temperatures and changed oceanic circulation patterns, may lead to the disintegration of the current ice shelves of QNP. With the removal of the protective ice shelf, newly exposed coastal shorelines would be more susceptible to erosion (Maxwell, 1997). Increased ice break-up could also lead to increased shore scouring by large detached blocks, causing the formation of more ice-pushed ridges.

Icefields and glaciers dominate the landscape of QNP (Parks Canada, 1994). According to Svoboda (1995), "[a]s the Arctic Ocean warms under the greenhouse effect, increased precipitation will eventually result, perhaps shifting the high arctic climate into snow accumulation mode...According to this idea, the tenuous balance between snow deposition in winter and heat available for melting and sublimation in summer will tip toward accumulation, resulting in advances in the high arctic ice caps." This will likely hold true for the glaciers at higher elevations. Glaciers at lower elevations currently form through the accumulation of multiple layers of ice resulting from the refreezing of meltwater runoff. If warmer temperatures at lower elevations reduce meltwater refreezing, the amount of superimposed ice may also decrease, leading to a retreat of some of the glaciers at lower elevations. Snow ablation may be reduced by increased coastal fog and clouds generated by the open waters of the Arctic Ocean (Maxwell, 1997). This process may help maintain a positive mass balance in QNP glaciers (Parks Canada, 1994).

Continuous permafrost with large blocks of frozen ground ice are common in QNP (Parks Canada, 1994). If warmer temperatures support an increased active layer depth and cause ice blocks to melt, the terrain will become wetter and more dominated by thermokarst. This might support a greater abundance of plant species, and may potentially lead to increased formation of palsas. Furthermore, as the permafrost thaws and ground ice is exposed, river erosion of cut banks, channels tunnelling into terraces, and ground-ice slumps which mix with meltwater to produce mudflows, will become more common (Maxwell, 1997. If the ground warms substantially, cold-based glaciers of QNP may no longer be frozen to their beds, thereby resulting in increased bed abrasion, material erosion, and sediment deposition. Mechanical weathering may also increase as freeze-thaw cycling becomes more pronounced with increased moisture availability. This will result in more mass movements, such as solifluction, rockfalls, and active layer failures (Maxwell and Barrie, 1989).

QNP is one of most arid places in Northern Hemisphere (Parks Canada, 1994) and vegetation growth is currently limited to oases within a polar desert. As air temperatures warm and ground moisture increases with more precipitation and a deeper active layer, the growing season will be extended (Press *et al.*, 1998; Chapin *et al.*, 1997). Biological production may rise with greater rainfall, a longer season and more soil nitrogen availability. This will result in increased plant growth in areas that are not severely disturbed by intense wind action and/or frost heaving. For example, the herbaceous bioclimatic zone of QNP may see increased colonization of tundra plants as warmer air

temperatures combine with the existing humidity to give more favourable growing conditions. In addition, the herb-transition zone may shift to a higher altitude under the new climate regime, while the enriched prostrate shrub zone may expand its range

Muskox and Peary caribou in QNP will likely benefit from the increased availability of summer forage. Increased snow depth and/or the presence of ice layers in the snow will increase energy expenditure in foraging. The net result may be lower nutritional levels and reproductive success (Hansell *et al.*, 1998; Gunn, 1995; Maxwell, 1997). In addition, caribou are sensitive to insect harassment (Parks Canada, 1994) and may be forced into less productive, higher altitude habitats if insect populations increase significantly (Brotton and Wall, 1997). Russell (1993) predicted the combined stress would result in parturition rate declines of 40% to complete reproductive failure in worst case scenario.

Some sea mammals (e.g., whales) may benefit if sea ice decreases along the coast of the Arctic Ocean (Ono, 1995). However, species which depend on snow conditions for shelter and rearing young (such as polar bears, ringed seals, arctic foxes and arctic hares), may be adversely impacted by a warmer climate. For example, polar bears and ringed seals give birth to their young in the shelter of snow dens. Unseasonable spring warming can destabilize the snow dens, exposing young to intolerable outside temperatures. The distribution of sea mammals may be altered as ice thickness and strength changes. Any shifts in prey populations will have an effect on large predators such as arctic wolves, polar bears as well as scavengers like foxes.

Aquatic ecosystems may be affected by increased stream flows, erosion and sediment loads. Arctic char spawning and overwintering habitat may increase if water depth increases and ice thickness decreases.

Archaeological sites dating back approximately 4000 years are at risk in areas where flooding and erosion might increase along rivers and lakes. Coastal sites will be less affected because of ongoing uplift of the land. Park infrastructure will likely be affected by increased geomorphological processes such as solifluction, and mass wasting. Tourism opportunities in the park will probably not increase substantially because of remoteness and the cool, short summer seasons (i.e., temperatures are projected increase to 0°C under doubled-CO_2 scenarios).

3.6.5 *Tuktut Nogait National Park*

Tuktut Nogait National Park			
DATE ESTABLISHED	1996		
LOCATION	Northwest Territories – Park Geocentroid: 68.64°N, 121.95°W		
SIZE	16,340 km²		
FEATURES	• Tundra Hills Natural Region • Rivers, canyons, waterfalls • Tundra landscape • Calving grounds for Bluenose caribou herd • Muskoxen, wolves, grizzly bears		
Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+4.0 to +5.0	SPRING	-5.0 to +19
SUMMER	+2.0 to +5.0	SUMMER	0.0 to +20.0
FALL	+2.0 to +6.0	FALL	+7.0 to +26.0
WINTER	+4.0 to +7.0	WINTER	-24.0 to +25.0

There is very little information on the Melville Hills region in which Tuktut Nogait National Park (TNNP) is located, but some general conclusions about the potential climate change can still be drawn. Climate change projections for TNNP suggest a warmer, wetter climate. Warmer temperatures will extend ice-free seasons, promote a shift to discontinuous permafrost, and increase the frequency of freezing rain during fall and winter months. Increased annual precipitation would likely lead to additional winter snow accumulation, greater river volumes and flow rates, and increased soil saturation.

The official boundaries of TNNP do not extend directly to the Amundsen Gulf. This coastal area heavily influences the local climate and therefore the impacts of global warming on the coastal processes in this area must be considered. Above all, TNNP will be affected by extended ice-free periods due to earlier sea ice break-up and later formation (Maxwell, 1997). This may result in increased fogginess and cloudiness in the northern areas of the park (Zoltai *et al.*, 1992).

Increased snow accumulation and greater spring runoff may lead to higher river levels, increased water velocity, and possibly the formation of new drainage channels (Rouse *et al.*, 1997). Spring peak flows will also occur slightly earlier in the year (Cohen, 1997). These changes in park hydrology might increase erosion of cliff bases and possibly lead to more rock falls within the deep river canyons. There will be more sediment accumulation in depositional areas.

Characteristic geomorphological aspects of TNNP include previously glaciated areas with features such as drumlins and eskers, unglaciated areas with gentle slopes and well established drainage systems, and the products of isostatic uplift such as raised beaches and marine clay deposits at high elevations (Parks Canada, 1997a; Zoltai *et al.*, 1992). In

addition, there are several unusually large ice-wedge polygons in unglaciated terrain, and a few very large pingos. Many of these features arise because the park is currently underlain by permafrost. The boundary of the discontinuous permafrost zone is expected to move hundreds of kilometres north (Maxwell, 1997; Svoboda, 1994). The result will be a shift from continuous to discontinuous permafrost in TNNP. With a deeper active layer and increased precipitation, overland water flow may increase and low-lying soils will become more saturated. In addition, more overland water flow might lead to increased erosion of drumlins, eskers, and pingos. Landforms associated with a colder climate (e.g., pingos, ice wedges, patterned ground) are also at risk of disappearing, as they will cease to form under a warmer climate regime.

Currently TNNP contains a relatively high diversity of both semi-polar desert and arctic tundra vegetation communities. The region also contains rare plant species from Beringia, an expanse of land that was unglaciated during the last ice age (Zoltai *et al.*, 1992). Current plant species assemblages will undergo several changes under a warmer climate. Range expansions can be expected for plants that thrive in wet conditions, such as sedges, willows, and cottongrass. There may be increased invasion of boreal species from the south. Slow growing tundra vegetation (e.g., lichens, cushion plants) may be outcompeted and forced to higher elevations (Press *et al.*, 1998; Landhausser and Wein, 1993). Lenihan and Neilson (1995) projected the high arctic desert vegetation to be augmented by more subarctic evergreen communities or shift to boreal evergreen species.

These changes in vegetation distribution and abundance will affect park wildlife, particularly caribou and muskoxen. The Bluenose caribou herd presently selects windswept, dry, and relatively insect-free areas in TNNP for calving (Zoltai *et al.*, 1992). However, increased precipitation and temperature may lead to wetter soils and changes in vegetation availability. Warmer conditions and more standing water would increase insect harassment of caribou. Wetter soils may also lead to decreased availability of ideal (dry) calving grounds. Vegetation changes in calving grounds may also limit herd productivity as caribou nutritional status declines (Brotton and Wall, 1997). The Bluenose caribou herd will also be affected by changes occurring in their overwintering grounds, such as increased snow depth and more ice encrusted vegetation (see Aulavik National Park and Auyuittuq National Park for further discussion).

The muskox population at TNNP is particularly at risk from vegetation shifts, since they are at the southern edge of their arctic desert range. Summer forage availability might increase with more lush vegetation, however populations would suffer if winter conditions lead to a deeper snow cover with more ice layers. Furthermore, muskoxen may be extirpated from TNNP if taiga vegetation becomes overly abundant (Gunn, 1995). Changes in caribou and muskoxen populations will undoubtedly lead to changes in predator populations, such as grizzly bears, wolverines, and wolves.

Small mammals, such as collared lemmings and arctic hare, are common in TNNP. If vegetation changes and increased soil saturation lead to the anticipated declines in

lemming populations (Kerr and Packer, 1998), predators such as the vulnerable tundra peregrine falcon and jaegers can be expected to decline as well. TNNP's birds of prey might also be affected by reductions in available nesting sites associated with increased cliff erosion along rivers.

The tourism potential for TNNP may be improved by climate change. Canoeing and rafting along the Hornaday and Little Hornaday Rivers might increase as water volumes increase. Conversely, these sports may be negatively affected if water currents become too swift and create more hazardous rapids that are suitable only for experts. Overland hiking and camping may become more difficult if tussock-forming vegetation (e.g., cottongrass) becomes dominant. The length of the season for these pursuits would increase with milder temperatures. Sites of historic and archaeological interest, such as the ancient driftwood along the shore of Lake Hornaday may also be negatively affected by increased wave action and shoreline erosion.

3.6.6 Vuntut National Park

Vuntut National Park	
DATE ESTABLISHED	1995
LOCATION	Yukon Territory – Park Geocentroid: 68.29°N, 139.54°W
SIZE	4,345 km^2
FEATURES	• Northern Yukon Natural Region • Old Crow Flats wetland complex (designated Ramsar site) • High bird species richness in summer • Migration corridor for Porcupine caribou herd • Abundant moose, all three bear species, muskrat • Unique fossils from Beringia

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
TEMPERATURE CHANGE (°C)		PRECIPITATION INCREASE/DECREASE (%)	
SPRING	+4.0 to +6.0	SPRING	-4.0 to +14.0
SUMMER	+2.0 to +5.0	SUMMER	+12.0 to +28.0
FALL	+3.0 to +5.0	FALL	+4.0 to +13.0
WINTER	+4.0 to +6.0	WINTER	-3.0 to +33.0

Increased year-round temperatures in Vuntut National Park (VNP) will likely lead to earlier snow-pack melt, decreased ice thickness, longer open-water season, deeper active layer in permafrost areas, treeline expansion, and increased forest fire frequency. Implications of a wetter climate include increased snow accumulation, increased spring runoff volumes, higher river volumes, and faster river flow. These climatic, hydrologic, and geomorphologic changes associated with climate change will undoubtedly affect park flora, fauna, and sites of archaeological significance. See section 3.6.3 for further discussion of other regional implications of climate change.

Changes in park hydrology, such as reduced ice thickness on all water bodies, larger spring runoff volumes, and slightly earlier spring peak flows (June rather than July – Clair *et al.*, 1998), could lead to increased riverbank erosion, slumping, and sediment load in the river systems of VNP (Maxwell, 1997).

Thousands of small, shallow lakes are characteristic of VNP (Parks Canada, 1995). Rouse *et al.* (1997) noted that it is very likely that a deeper active layer and increased precipitation will lead to the formation of new drainage channels, the removal of excess water, and a drawdown in local water tables. Many new ponds and lakes could be formed as local topography and fine-textured soils retain much of the water that is currently frozen (Rouse *et al.*, 1997). It is therefore difficult to project exactly how the wetlands of the Old Crow Flats will respond to warmer, wetter temperatures, and harder still assess the consequences for vegetation and wildlife. For example, if the new climatic regime leads to improved water drainage and further permafrost degradation, the extent of wetland coverage will be dramatically reduced (Hansell *et al.*, 1998; Maxwell, 1997). Conversely, if the water table level does not change, northern peatlands may remain intact in spite of the projected climate changes (Maxwell, 1997).

Currently, VNP is underlain by continuous permafrost. Under a warmer climate the discontinuous permafrost zone is expected to expand hundreds of kilometres north, (Svoboda, 1994) thereby changing the geomorphological properties of VNP. Warmer temperatures will result in a deeper active layer, increased thaw and erosion, increased large scale mass wasting, more slope movements, and changes in mechanical soil properties such as creep and relaxation effects (Maxwell, 1997; Rouse *et al.*, 1997; Maxwell and Barrie, 1989). In addition, since the continuous permafrost layer currently supports the development of peat plateaux, thermokarst pools, ice wedge polygons, palsas and peat mounds (Rouse *et al.*, 1997), the prevalence of these features might decrease under a warmer climate regime.

The wetlands of VNP currently support a large number of breeding and staging waterfowl (Parks Canada, 1978). Significant declines in these waterfowl populations can be expected if increases in temperature and precipitation lead to the loss of the valuable wetland habitat of the Old Crow Flats. Changes in the hydrology of this wetland complex may also affect muskrat populations. If better drainage, increased sedimentation, and/or a deeper active layer lead to shallower lakes, the aquatic vegetation upon which muskrat depend during winter could become more susceptible to frost. This may result in decreased winter survival of muskrat. However, if temperatures warm enough for reduced ice formation on lakes and rivers, aquatic vegetation may not be affected by frost and the warmer temperatures would favour muskrat populations. Muskrat populations may also be affected by changes in fall and winter stream flow regime, which could restrict access to critical winter food supplies. Any changes in muskrat populations will inevitably lead to declines in mammalian and avian predator populations (Watson *et al.*, 1973).

Increased water volumes in streams and rivers could also lead to increased availability of overwintering habitat for freshwater species such as arctic grayling, longnose sucker, and least cisco. The quality of salmon spawning grounds would decline in areas with increased stream flow, erosion, and sedimentation (Bryan *et al.*, 1973). Conversely, more upstream spawning areas may become available with more water flow, thereby mitigating some impacts of increased stream flows on fish populations.

It is likely that under climate change the treeline will move 200-300 km north, thereby allowing willow and spruce to become more dominant in the regions surrounding Old Crow Flats (Maxwell and Barrie, 1989). There may also be increased wildfire frequency, which may result in further degradation of the permafrost layer (Landhausser and Wein, 1993) and consumption of peat down to the water table.

The moose population of VNP may benefit from climate change if wintering habitats of high cover and food availability, such as deciduous shrub areas, become increasingly available with the invasion of taiga vegetation. Unfortunately, ungulate mobility and access to food supply in winter months may be limited by heavier snowfall (Brotton and Wall, 1997). An increase in insect harassment could also negatively affect caribou populations during summer months (Russell, 1993). Grizzly bears may also benefit from increased shrub cover and increases in moose populations, so long as the habitat does not become dominated by larger tree species. Conversely, grizzlies may be negatively affected if caribou migration routes change under a new hydrological regime and/or if caribou populations suffer from changes occurring on their calving and overwintering grounds (see discussion in Ivvavik National Park).

Most of the land in VNP was unglaciated during the last ice age. Consequently, VNP has been referred to as an area of 'unequalled value for paleoecological research' (Parks Canada, 1995). Unfortunately, the fossilized remains of prehistoric culture could be affected by changes in hydrology and vegetation. If peatlands disappear, these fossilized remains will be exposed to damaging oxidizing agents and will decompose. In addition, increased erosion along the Old Crow River may lead to the elimination of many sites of archaeological interest identified in park inventories (Parks Canada, 1978).

The length of season for recreational pursuits such as backcountry camping, hiking and fishing may be increased with warmer temperatures. Conversely, tourism might suffer if the summer waterfowl congregations diminish, if mosquitoes and flies increase, or if some of the unique historical aspects of the park are lost.

3.6.7 *Wapusk National Park*

Wapusk National Park	
Date Established	1996
Location	Manitoba – Park Geocentroid: 57.53°N, 93.12°W
Size	11,475 km^2
Features	• Central Tundra Natural Region • Vast expanses of peaty lowlands • Coastal and inland bird nesting/feeding/staging areas • Site of one of the largest polar bear denning areas • Taiga-tundra ecotone with underlying permafrost

Projected Climate Change – Range of Four Doubled-CO_2 Scenarios			
Temperature Change (°C)		Precipitation Increase/Decrease (%)	
Spring	+2.0 to +5.0	Spring	-1.0 to +22.0
Summer	0.0 to +5.0	Summer	+6.0 to +39.0
Fall	+2.0 to +4.0	Fall	+2.0 to +16.0
Winter	+4.0 to +8.0	Winter	+4.0 to +30.0

Located on the coast of Hudson Bay, Wapusk National Park (WNP) is known for its polar bear population and extensive coastal bird communities. As with most other northern parks, projected climatic changes for WNP include warmer year-round temperatures and increased precipitation. Warmer temperatures will lead to significantly less ice formation in Hudson Bay, reduced ice thickness, loss of permafrost, increased fire frequency, and earlier spring melts. Consequences of increased precipitation include increased snow accumulation, increased frequency of freezing rain, and increased spring runoff. Annual runoff in the region is projected to decline by approximately 6% (Clair *et al.*, 1998). These changes will likely result in dramatic changes in the ecology of WNP due to its location at the taiga-tundra ecotone.

The coastal flora and fauna of WNP are particularly vulnerable to global climate change because of the radical changes anticipated in the sea ice of Hudson Bay. As with many of the other coastal northern parks, warmer temperatures year round may lead to later sea-ice formation and earlier break-up. However, due to the southerly extent of Hudson's Bay, Hansell *et al.* (1998) suggested that it may become ice-free all winter, thereby forcing many marine mammals further north (Ono, 1995). Seasonal movements of polar bears in the Hudson Bay lowlands are determined by sea ice conditions and prey availability (Clark, 1996). Since the polar bear population at WNP is already near the southern range limit, they will probably be forced north of WNP if seals migrate or if sea ice ceases to form during the winter months (Clark, 1996). The decline in female bear body weight index (from 55 to 49) and average births (0.99 to 0.84) over the past 20 years (Stirling, 1998) and sightings of black bears in Churchill (Scott, 2000) may be an early indicator of climate change in the WNP area.

Sea-level is projected to rise by 0.5m by 2100 (Forbes *et al.*, 1997). The area currently experiences isostatic rebound of approximately 1.0 m. per century (von Moers and Begin, 1993; Hik *et al.*, 1992). This would more than offset the rising sea-levels and the land will continue to rise out of Hudson Bay, but at a slower rate than in the recent past.

A continuous layer of permafrost underlies the terrain at WNP, and gives rise to its boggy peatlands and patterned ground. Warmer temperatures and reduced winter snow cover could lead to a deeper active layer, with several implications for the geomorphological features of the Hudson Bay lowlands. First, the soils of the area would become liquefied, thermal erosion would increase, and freeze-thaw cycling would become more prevalent (Hon, 1995). In addition, changes in the underlying permafrost layer could induce terrain slumping which will affect drainage patterns and river sediment loads. Peat plateaux, thermokarst pools, palsas, and peat mounds, which are all currently supported by continuous permafrost, would also be at risk with global warming. Finally, underground water storage capacity would increase and drainage might improve. Consequently, overland flow would be reduced and many of the patchy arctic wetlands and peatlands, characteristic of this region, would disappear (Rouse *et al.*, 1997).

Changes in active layer depth will have implications for the flora of WNP. The deepening active layer will be warmer and microbial activity, nutrient mineralization, and nutrient availability will increase (Press et al., 1998; Svoboda, 1994). This would remove some of the current environmental constraints in the north and open new opportunities for faster growing and more competitive southerly species (Hansell *et al.*, 1998; Landhausser and Wein, 1993). Another potential impact of increased active layer depth in the peatlands of WNP is that water levels will drop, resulting in increased aerobic conditions, oxidation, and decomposition (Rouse *et al.*, 1997). A combination of all these factors would lead to a dramatic decline in peat formation and storage, thereby resulting in a gradual shift away from peatland plant communities. Maxwell and Barrie (1989) project that the treeline will move north 200-300 km with projected warming. Lenihan and Neilson (1995) project a shift from subarctic evergreen to boreal evergreen communities under two doubled-CO_2 scenarios. As the dominance of the taiga increases and water drainage improves, fires may become more frequent. Doubled-CO_2 may increase the fire weather index (FWI) by 1.0 to 1.5 times in the region (Thompson *et al.*, 1998). This will temporarily remove the insulating vegetative layer, and lead to further deepening of the active layer and increased invasion of southerly (boreal forest) species (Maxwell, 1997). Fires in the park are likely to continue to burn down to the water table, thus forming new ponds and marshes. Although the presence of trees often leads to the reformation of permafrost due to their insulating value, permafrost reformation in WNP will not likely be widespread, but will rather be restricted to sites dominated by cooler microclimates.

The extensive peatlands of WNP are currently used by hundreds of thousands of ducks, geese, shorebirds, and terrestrial bird species during the summer months (Chartier, 1988). With the aforementioned changes in geomorphology and vegetation, there may be decreased availability of coastal staging areas (Boyd and Madsen, 1997) as well as

decreased inland habitat, especially for waterfowl. However, ponds created by peat burning may mitigate this effect. In addition, since lesser snow geese "engineer" their coastal habitat, any changes in their foraging behaviour (e.g., arrival before spring vegetation emerges because of increased winter precipitation) could alter the community structure of coastal marshes. This would, in turn, have an impact on other species using these communities such as invertebrates, grazing ducks, and shorebirds (Hik *et al.*, 1992). The bird communities of WNP may therefore decrease as they are forced further north to find more suitable nesting and foraging grounds.

Caribou will also be affected by vegetation changes. Depending on how far north the herds must migrate in search of food, distances of fall migration to the margins of the taiga will change and overwintering grounds may change as well. On these wintering grounds, the nutritional status of caribou may decrease if winter snow depth increases and freezing rain encrusts vegetation (Gunn, 1995). Snow depth greater than 60 cm restricts caribou movement and foraging (Russell, 1993). If soil drainage increases enough to decrease the wetness of the lowlands, summer insect harassment may decrease. However, Russell (1993) projected the abundance of mosquitoes and blackflies to increase with milder and wetter springs, coupled with a longer warm season. The area of snowpatch habitat available to caribou for insect avoidance and thermoregulation will also decrease.

As with many other northern parks, global warming may lead to damages to park infrastructure (e.g., buildings, boardwalks, roads etc.) as permafrost melts. In addition, tourism at WNP would suffer significantly if polar bear populations were extirpated in the park. There are also many sites of historic significance in the region that might suffer from hydrological and geomorphological changes ensuing from increased temperatures and precipitation.

4.0 Conclusion

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The preceding discussion has identified a wide range of direct and indirect climate change impacts that could effect the ecology of Canada's National Parks. Table 7 summarizes the cross-cutting impacts that are anticipated to effect the national parks in each region of Canada. It is important to emphasize that climate change simultaneously represents a threat and opportunity to different species and ecological communities across Canada. Consequently, the relative significance of climate change for protected areas in each region and more so, individual parks will differ. This analysis has not attempted to rank the sensitivity of each national park to climate change. The study has revealed that the number of national parks identifying climate change as a significant ecological stressor should increase substantially in subsequent State of the National Parks reports.

Table 7 - Regional Cross-Cutting Climate Change Impacts in National Parks

ATLANTIC PARKS
▪ sea-level rise (exacerbated by tectonic subsistence) and greater storm intensity and frequency
▪ increased coastal erosion and salt water intrusion
▪ altered marine-terrestrial interface (dune system, tidal pools, mudflats, salt marshes and estuaries)
▪ changes is ocean currents with a possible cooling influence for coastal water temperatures (expansion of cold-water species)
▪ increased forest fire frequency
▪ increased storm, fire, and pest disturbance (altering successional trajectories)
▪ loss of boreal forest to temperate forest
▪ reduction or isolated extirpation of arctic-alpine species and communities
GREAT LAKES – ST. LAWRENCE BASIN PARKS
▪ lower average Great Lake water levels and summer stream flow
▪ increased lake and stream water temperatures
▪ reduced lake ice-cover and earlier spring freshet
▪ loss of cold-water fish habitat and altered breeding/spawning and migration patterns
▪ reduction of significant wetland areas
▪ increased forest fire frequency and intensity
▪ exacerbated acid rain stress
▪ increased forest disease outbreak and insect infestations
▪ altered successional trajectories and loss of mature forest habitat
▪ loss of boreal forest to temperate forest
▪ expansion of southern exotics

Table 7 - Continued

PRAIRIE PARKS
■ altered seasonal hydrology (earlier and greater spring freshet, reduced base summer flows and warmer stream temperatures, reduced period of ice cover) ■ increased frequency and intensity of drought stress ■ reduced wetland area ■ altered waterfowl breeding and migration patterns ■ altered fish species composition (expansion of warm water species) ■ increased forest fire frequency and intensity ■ increased forest disease outbreak and insect infestations ■ loss of boreal forest to grassland and temperate forest ■ expansion of southern exotics
WESTERN CORDILLERA PARKS
■ altered seasonal hydrology (earlier and greater spring freshet, reduced period of ice cover) ■ increased snow pack and avalanche activity ■ variable mass balance of glaciers (low elevation glaciers projected to thin and retreat while those with higher accumulation zones may surge with increased winter precipitation) ■ possible temporary elevation of river toxins resulting from increased glacial melting ■ altered river ecology ■ latitudinal and elevational migration of ecozones ■ loss of some Alpine assemblages from mountain peaks ■ increased forest fire frequency and intensity ■ increased forest disease outbreak and insect infestations ■ increased wintering zone pressures and impaired migration of large animals
PACIFIC PARKS
■ sea-level rise (moderated by on-going isostatic rebound) ■ increased ocean surface temperatures ■ greater storm intensity and frequency ■ increased salt water intrusion ■ reduced nutrient upwelling and increased incidence of red tide blooms ■ reduced cold water habitat and expansion of southern fish species populations ■ altered seasonal hydrology (earlier and greater spring freshet) ■ altered spawning and migration patterns ■ loss of Alpine species from higher elevations ■ accelerated forest insect and disease cycles
ARCTIC PARKS
■ northward expansion of treeline (impaired by soil conditions) ■ increased permafrost active layer and thawing (subsequent altered drainage patterns) ■ sea-level rise (variably moderated by isostatic rebound or exacerbated by subsistence) ■ reduced sea and lake ice seasons and altered sea mammal distributions (polar bears, whales) ■ increased snow pack and ice layers (reducing browsing accessibility for ungulates) ■ greater severity and length of insect seasons (increased harassment of ungulates) ■ altered migration patterns and diminished genetic exchange among arctic islands ■ potential for altered predator-prey relationships

Climate change will be superimposed on the range of current ecological stressors outlined in the 1997 State of the Parks report (Parks Canada, 1998a). For some species, these stressors may matter more than climate change, particularly in the short-term (the next 25 years). Nonetheless, climate change will be a dominant factor in ecological protection in the twenty-first century and serve as a catalyst for change for organizations with an ecological conservation mandate. Lopoukhine (1990: 324) argued " ... climate change is poised to alter the rate of evolution in (Parks Canada) policies and Act." Although the influence of climate change on Parks Canada policy in the interim decade appears to have been minimal, this study supports that conclusion.

The strategic role of Parks Canada in an era of climate change requires much analysis and deliberation. Fundamentally, Canadians, the government of Canada, and the scientific community need to engage in a dialogue regarding what it is Parks Canada will endeavour to protect as climatic conditions change. Three very different policy directions could be adopted:

1. continue to protect current ecological communities within national park boundaries;
2. accept the ecological response to climate change and allow evolutionary processes to take place unhindered;
3. maximize the capacity of species and ecological communities to adapt to climate change through active management strategies (e.g., fire suppression, species translocation, invasive species suppression).[11]

To pursue the first course of action, against evolutionary processes, would be unsustainable.[12] Whether prolonging relic assemblages under evolving climate conditions is compatible with Parks Canada's mandate to maintain ecological integrity, also requires consideration.

Ecosystems have some inherent ability to adapt to climate change, though this resilience is being diminished by other significant ecological stressors. It could be therefore argued that they should be allowed to do so without further human interference. This would require a departure from the current scientific based management approach. It is also questionable whether Canadians would be willing to accept the potential impacts of climate change on their national parks and the species they protect. Where populations of valued or symbolic species declined rapidly or were at risk of extinction, a powerful interventionist lobby is sure to emerge.

Lopoukhine (1990) asserted that an active management regime is the only recourse for protected area agencies in an era of climate change. This position is justified because the magnitude of projected human-induced climate change will be beyond the adaptive capacity of some species. Furthermore, although ecosystems are resilient to climatic shifts, humans have disturbed the natural processes (e.g., wildfires cycles and genetic interchange) that are integral to the ability of natural systems to adapt to climate change.

Although an active management regime to augment the capacity of natural systems to adapt to climate change is warranted as compensation for human interference in natural

processes, it would nonetheless heighten ethical and scientific dilemmas for park managers. Intervention strategies, for the most part, would be species specific. With limited conservation resources, there will be critical questions regarding which species should receive assistance. Park managers will be placed in a position of having to determine whether the continued protection of a threatened species that may no longer have suitable habitat in the park in question or a role in the emerging ecological community is reasonable. There will be greater pressure to assist species that are valued by society, perhaps even to the detriment of other species. The political pressure that drove the translocation of Plains Bison to Wood Buffalo National Park, despite the known risk of hybridization and introduction of tuberculosis to resident Wood Buffalo, may foreshadow decision-making pressures Parks Canada will face.

The level of scientific certainty required for active management strategies will also be difficult to assess, both in terms of determining when intervention is warranted and the probability of unanticipated consequences. Our limited understanding of the enormously complex dynamics within ecosystems and their capacity for non-linear change, indicates ecosystem-level response to climate change may never be entirely predictable (Myers, 1995; Malcom and Markham, 1996). By extension, the consequences of interventionist strategies intended to advance the capacity of ecosystems to adapt will be equally unpredictable. The information requirements for an adaptive management approach to climate change will be intensive and require additional resources for scientists and park planners to engage in a continuous cycle of monitoring, planning and feed-back learning.

Though not the primary focus of this study, it is evident that climate change will alter recreational opportunities and visitation patterns within the national parks. This will also have important implications for tourism revenues within the national parks and surrounding communities. Our system of national parks represents a major tourism resource in Canada. Tourism expenditures attributable to national parks visits (approximately $1.2 billion in 1994/95 - Parks Canada, 1998a) have a significant effect on the economies of many communities. Tourism revenues are increasingly important to Parks Canada as well. Until 1994, Parks Canada was funded entirely from federal government appropriations and revenues generated from park visitors were not retained. Although government appropriations continue to fund the creation of new parks and the ongoing protection of heritage resources, changes to Parks Canada's business plan requires that revenues generated by park visitors now pay for certain visitor services. The portion of Parks Canada's budget derived from tourism revenues exceeded $71.4 million in 1998/99.

Wilton and Wirjanto's (1998) research indicated warmer summer temperatures have a positive influence on domestic tourism in Canada. When combined with growth trends in global tourism (World Tourism Organization, 1998) and increased demand for nature-based recreation (Foot, 1990), visitation to Canada's national parks should continue to increase (notwithstanding some inter-annual variability).

Parks Canada (1998a) has recognized the significance of flooding, forest fires, and weather extremes for year to year fluctuations in visitor numbers. As discussed throughout section three, these and other factors related to outdoor recreation (e.g., snow conditions, wildlife migrations, water levels) are sensitive to climate change. Whether changes to the character of the natural landscape, wildlife and cultural features in national parks would diminish the appeal of certain parks to visitors is uncertain. National parks will continue to provide natural, relatively 'unspoiled' landscapes in some form or another and these are likely to hold their appeal regardless of the ecosystem changes resulting from climate change.[13] Nonetheless, it is foreseeable that the loss or greater restriction of a particular recreational activity (e.g., beach activities in Piping Plover nesting areas) or the loss of prominent species (e.g., polar bears in Wapusk National Park) could have a detrimental impact on visitor numbers in certain parks.

4.1 Next Steps ...

The substantial knowledge gaps identified throughout this analysis point to the need for a program of research to examine the ecological and tourism implications of climate change in the national parks. Some initial research directions include:

National Parks System Plan Assessment

The disjoint between the biogeographical changes brought about by human-induced climate change and static national park boundaries, signifies the need to evaluate the ability of the current national parks system to provide habitat for the species protected within its boundaries and those likely to require protection as a result of altered climatic regimes. Canadians are likely to place greater demands on the national parks system to protect species and ecosystems under stress from climate change. The national park system plan will undoubtedly need to expand if Parks Canada is to continue to fulfil its ecological protection mandate.

In the interim, it would be prudent for Parks Canada to integrate climate change into the park selection and design process (e.g., in criteria to identify candidate areas and determine the size and configuration of new parks[14]). For example, a review of the lands being reserved for future parks (Parks Canada, 1998a) against the north-south orientation criteria recommended by Rowe (1989), revealed the orientation of most of these proposed areas is not theoretically optimal for climate change adaptation. In particular, the East Arm of Great Slave Lake and perhaps Wager Bay could be reconsidered. Considering the complex and politically sensitive process of establishing new national parks, the salience of climate change as a selection and design criteria is likely to be low at this time, but increase over coming decades.

An important adaptive strategy for protected area and conservation planners is to enhance the connectivity of the nation's protected area network by improving migration opportunities through the landscape[15]. Although a species may have the ability to respond to climate change through migration, it can only do so if migration opportunities exist. Quon (1993) developed a qualitative framework to evaluate the relative contribution of individual nature reserves to landscape migration[16]. As understanding of species and ecosystem response to climate change improves, gap analysis could be used to identify key areas for future protection within the national parks system or another component of Canada's broader network of protected areas. Assessing migration opportunities and identifying connectivity gaps will be important for strategic planning.

Co-Benefit Opportunities: Ecological Protection through Climate Change Mitigation

The need to expand the national park system and improve the connectivity of the national parks with other components of Canada's broader protected areas network has been elucidated in the scientific literature for decades. As the preceding discussion indicated, climate change will add one more major impetus to do so. As Canada and other industrial nations push forward toward their Kyoto Protocol commitments, the potential for carbon sequestration through land management practices may provide a unique opportunity for landscape-level habitat restoration and the expansion of protected areas. This opportunity to enhance Canada's protected areas network and biodiversity should not be underestimated. All levels of government and industry will be receptive to meaningful carbon sequestration plans and associated carbon credits.

As Cutright (1996) and Sawhill (1996) indicate, conservation organizations and utilities in the European Union and the United States have already engaged in projects that would provide ecological protection through carbon sequestration (a co-benefit strategy). There is a need for protected area stakeholders (government agencies, NGOs, citizens) to explore in earnest the feasibility of various mechanisms that would attract investment in substantive ecological restoration-carbon sequestration projects in Canada (i.e., alternative property regimes and credit trading systems) and build partnerships that would operationalize this strategic opportunity.

Vulnerability Analysis of Individual National Parks

There is a strong need for more detailed impact assessment at the regional and individual park level due to the regional and local character of climate change impacts for ecosystem structure and productivity. Work by Gomer (1999) and Hui (2000) to generate more detailed climate change impact inventories and initiate adaptation capacity building among local national park stakeholders represent progress. Similar exercises are required in each national park. In park areas where development pressures are particularly acute, a more in-depth integrated assessment, informed by the procedures identified in (Yin and

Cohen, 1994), should be considered. The Banff-Jasper corridor is one prominent candidate.

Future studies also need to examine park management objectives explicitly. Examining the implications of climate change for each park's specific objectives and 'desirable state' is an important next step in assessing the vulnerability of each park to climate change. Assessments of park management plans might include the following elements:

- identification of historical and archaeological sites at risk from climate change impacts and plans to excavate or relocate sites that cannot be protected;
- analysis of the sensitivity of Canada's species at risk[17] to climate change (including an inventory of possible extinctions);
- examination of how climate change might effect the invasibility of park habitats; and
- how current management practices may influence evolutionary trajectories as climate conditions change.

The development of a climate change vulnerability index to allow comparisons among the national parks, would be a useful tool for prioritizing future research and resource allocations.

Climate Change Monitoring

The relatively undisturbed nature of national park landscapes make them a valuable resource for monitoring ecological changes related to global climate change. The Ecological Monitoring and Assessment Network (EMAN), being co-ordinated by Environment Canada's Ecological Monitoring Co-ordinating Office, is a very positive step in facilitating the type long-term, multi-disciplinary monitoring of ecological conditions needed to detect ecological trends related to climate change. Expansion of the network to all national parks, even if only for keystone or indicator species, would be significant achievement. The ability to effectively detect and monitor the effects of climate change adds urgency to the completion of ecological inventory work in the national parks.

Tourism Assessment

Climate change will alter recreational opportunities and visitation patterns within the national parks. Staple (1994:20) indicated, " ... projecting how variations in climate may affect future recreational opportunities is an important factor in formulating sustainable management decisions which protect the ecological integrity of park(s)." Unfortunately, Wall (1998:614) has pointed out that, "Although the implications for tourism are likely to be profound, very few researchers have begun to formulate relevant questions, let alone develop methodologies which will further understandings of the nature and magnitude of the challenges ..." posed by climate change.

Several research questions related to national park-based tourism in Canada need to be examined. What is the sensitivity of park based tourism to current climate variability? How would projected climate change effect the conditions and experience of various recreation activities (e.g., season length, access and safety, infrastructure)? Would shifts in recreational activities or the need for additional infrastructure be compatible with park objectives? What are the economic implications (for Parks Canada and surrounding communities) of altered tourism patterns in the national parks?

Emergency Planning and Infrastructure

While not discussed at length in this report, emergency costs associated with forest fires, floods and avalanche management should increase under anticipated climate conditions. Inter-annual fluctuations aside, expenditures in 1994/95 and 1996/97 (approximately $4.3 and 2.5 million respectively – Parks Canada, 1998a) may become more typical or exceeded. Assessment of historical analogue years would provide better estimates of costs expected under climate change scenarios.

Some of the infrastructure within the national parks is also likely to be effected by climate change. With the exception of town sites (e.g., Banff and Wasagaming) much of the infrastructure in the national parks has a limited lifetime and is highly mobile. Normal replacement cycles will afford the opportunity to negate most infrastructure losses. Nonetheless, it would be prudent to design bridges, culverts and other long-term, hydrologically sensitive infrastructure with the capacity to handle greater extremes.

International Collaboration

The literature review for this analysis did not find any comparable climate change assessment of protected areas in other nations. There may be an opportunity for Parks Canada to take an international leadership role through further collaboration with academic institutions and other federal and regional agencies in the Scandinavian nations, Russia, China and the United States in particular.

Climate Change Roundtable on Protected Areas

Institutional change will be an important component of any protected area climate change strategy. Ecosystems do not honour political boundaries and inter-agency collaboration will be increasing important in an era of climate change. Climate change monitoring, impact research and adaptation strategies cannot be undertaken by a single agency or research institution. Agencies responsible for protected areas must overcome historic barriers to develop a more holistically managed network of federal, provincial and private lands dedicated to ecological protection. Equally, as southern species extend their range increasingly northward, Canadian protected area and natural resource management

agencies will need to develop better partnerships with their counterparts in the United States. Parks Canada should take a leadership position and initiate a national (and/or bi-national) climate change roundtable (composed of representatives from protected area agencies, the scientific community and other stakeholder groups) on climate change and protected areas. This inter-disciplinary working group would:

1. identify key research needs with regard to climate change and protected areas;
2. assess the feasibility of a range of adaptation pathways (e.g., fire and invasive management policies, park selection and design criteria, and refined park objectives) and greenhouse gas mitigation options (e.g., new fleet efficiency standards, piloting new renewable energy technologies, and the opportunity for landscape-level habitat restoration as part of national carbon sequestration strategies);
3. undertake a strategic visioning exercise to explore the role of protected areas in an era of human-induced climate change and what the national (or North American) protected area network would need to look like in 2050.

4.2 The Challenge Ahead

Climate change has the potential to undermine decades of notable conservation efforts in Canada and represents an unprecedented challenge to Parks Canada and conservation agencies more broadly. More optimistically, climate change mitigation may afford new opportunities for habitat restoration and the expansion of protected area networks.

A decade has passed since the initial inquiries of Peters and Darling (1985), Wein *et al.* (1990), and Lopoukhine (1990) into climate change and protected areas. Unfortunately their call for concerted action to address the vexing challenges posed by global climate change remains as relevant today.

[2] The IPCC is currently conducting its third periodic assessment of global climate change.

[3] At the time this analysis was conducted, Canada's national park system consisted of 38 parks that covered an area of 222,282 km^2. Simirlik National Park was added to the system in 1999, but was not included in this study.

[4] Hulme and Carter (1999) provide an authoritative discussion of the various types of uncertainty associated with climate change scenario development and impacts assessment.

[5] The unpredictability of human socio-technical change in the energy sector and the implications for GHG emission trajectories remains a large source of uncertainty in global climate change research.

[6] It is important to note that for each of the five scenarios generated, change in climate variables was calculated using the control simulation of the reference period, which corresponds to CO_2 levels in pre-industrial era. The magnitude of change projected is therefore relative to the pre-industrial climate (pre 1920) rather than the normal period (1961 to 1990) used to determine the climate baseline for each of the parks. Although new GCMs allow researchers to use simulated data from the 1961-90 period as the reference period, this was not possible with the three older models used and we opted for a consistent 'control' period or.

[7] The climate normal data for temperature and precipitation are derived from stations in each ecodistrict with 19 or more years of data.

[8] GIS data for the national parks was obtained from Parks Canada, Department of Canadian Heritage.

[9] The reader should consult the cited papers for additional information on the parameterization, assumptions, and global results of each model.

[10] A factor that could complicate this scenario is tectonic settling associated with an earthquake along the boundary of the Juan de Fuca and North American Plates west of Vancouver Island. When this event occurs, the west coast of Vancouver Island will drop by 1 to 2m, resulting in the inundation of many coastal features. Major earthquakes in the Cascadia Region have occurred historically every 300 to 900 years, with the last event probably occurring 300 years ago (Hyndman, 1995). As there is no way to predict when such an event may occur and this report will assume that sea-level changes brought about by climate change will gradually impact Pacific Rim National Park over the next century. This effect will eventually be dwarfed by a sudden change in sea-level resulting from tectonic settling (Thomson and Crawford, 1997).

[11] Reorienting national park policy to " ... preserve the adaptability and function of ecosystems rather than their current structure ... (Anderson *et al.*, 1998:146)," would compatible with Kay and Schneider's (1992) concept of ecosystem integrity: 'the ability of an ecosystem to self-organize over a broad range of organizational levels and spatio-temporal scales.'

[12] There will be a propensity to facilitate the continuation of current ecosystems, if only because they are within the term of reference of modern society and science. It is difficult to foresee the purposive design of management strategies that further the evolution of new assemblages that science has yet to comprehend.

[13] The Yellowstone National Park fires and Mt. St. Helen's eruption, illustrate that catastrophic landscape disturbances can actually increase visitor numbers (Wall, 1998).

[14] See Graham (1988), Rowe (1989) and Quon (1993) for a discussion of climate change related contingencies that should be considered in the selection and design of future park areas.

[15] Grumbine (1990:114) argued, "There is a broad consensus today among biologists that an integrated system of large nature reserves is necessary to protect biological diversity at genetic, population and landscape scales. ... Conservation biologists also agree that current species-level approaches must be augmented by landscape-level strategies that recognize ecosystem patterns and processes." The latter is particularly important for large-scale stresses such as climate change. In Sportza's (1998) opinion, the bioregional approach, combined with ecosystem management and community-based civics approaches offer the best direction for protected areas planning at the regional level. Parks Canada (1998a) has recognized the increasing importance of regional integrated planning and partnerships.

[16] This 'migration opportunity rating' is derived from four elements: the evaluated reserve, the reserve(s) to the north, the reserve(s) to the south, and the quality of the connective landscape features between them.

[17] Canada's national parks contain representative samples of almost 40% of Canada's species at risk.

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Appendices

Appendix A – Ecodistrict Based Temperature Normals (1961-90)

Appendix B – Ecodistrict Based Precipitation Normals (1961-90)

Appendix C – Climate Monitoring Station Nearest National Park Geocentroids

Appendix D – Climate Normals Derived from Nearest Climate Station Data

Appendix E - Projected Temperature Change from Five GCM Experiments

Appendix F - Projected Precipitation Change from Five GCM Experiments

Appendix G - Impact Assessment Checklist

Appendix H - Species List: Common and Latin Names

Appendix A – Ecodistrict Based* Temperature Normals (1961-90)

Park	Ecodistrict(s)	Mean Seasonal Temperature 1961-90 (°C)			
		Winter	Spring	Summer	Fall
Aulavik	Northern Arctic	-32.3	-22.0	2.1	-16.2
Auyuittuq	Arctic Cordillera/ Northern Arctic	-26.3	-17.9	2.9	-8.3
Banff	Montane Cordillera	-8.5	3.0	13.6	3.2
Bruce Peninsula	Mixed Wood Plains	-6.7	3.5	16.8	8.5
Cape Breton Highlands	Atlantic Maritime	-4.1	2.8	16.7	8.8
Elk Island	Prairies	-12.4	3.4	15.9	3.3
Quttinirpaaq	Arctic Cordillera/ Northern Arctic	-33.8	-24.1	2.2	-19.3
Forillon	Atlantic Maritime	-10.0	1.1	15.2	5.3
Fundy	Atlantic Maritime	-6.3	3.7	16.2	7.9
Georgian Bay Islands	Boreal Shield/ Mixed Wood Plains	-8.8	4.2	17.7	7.4
Glacier	Montane Cordillera	-6.4	5.2	15.6	4.9
Grasslands	Prairies	-11.6	3.8	17.5	4.2
Gros Morne	Boreal Shield	-6.7	0.8	13.9	6.1
Gwaii Haanas	Pacific Maritime	3.6	6.5	13.0	9.2
Ivvavik	Southern Arctic/ Taiga Cordillera	-24.7	-15.7	6.6	-9.1
Jasper	Boreal Plains/ Montane Cordillera	-8.2	3.6	14.0	3.5
Kejimkujik	Atlantic Maritime	-4.4	4.6	17.3	8.6
Kluane	Boreal Cordillera/ Pacific Maritime	-20.0	-2.3	11.3	-3.5
Kootenay	Montane Cordillera	-6.8	6.4	16.7	5.3
Kouchibouguac	Atlantic Maritime	-8.4	2.4	16.9	6.9
La Mauricie	Boreal Shield	-12.2	2.9	17.2	5.7
Mingan Archipelago	Boreal Shield	-11.4	-0.1	13.2	3.9
Mount Revelstoke	Montane Cordillera	-6.4	5.1	15.5	4.9
Nahanni	Taiga Plains/ Taiga Cordillera/ Boreal Cordillera	-25.3	-3.6	14.6	-5.1
Pacific Rim	Pacific Maritime	4.2	8.0	14.4	9.9
Point Pelee	Mixed Wood Plains	-3.4	7.7	21.3	11.5
Prince Albert	Boreal Plains	-16.7	1.0	15.2	1.8
Prince Edward Island	Atlantic Maritime	-5.8	2.5	16.9	8.5
Pukaskwa	Boreal Shield	-13.6	0.4	12.8	5.1
Riding Mountain	Boreal Plains/Prairies	-16.4	1.4	16.5	2.9
Saint Lawrence Islands	Mixed Wood Plains	-7.2	6.0	19.5	8.9
Terra Nova	Boreal Shield	-5.4	1.7	14.3	6.6

* - Current climate for each national park derived from a spatially weighted average of each ecodistrict in the park (percent of total park area).

Appendix A - Continued

Park	Ecodistrict(s)	Mean Seasonal Temperature 1961-90 (°C) Winter	Spring	Summer	Fall
Tuktut Nogait	Southern Arctic	-26.1	-16.4	5.6	-8.0
Vuntut	Taiga Cordillera	-28.1	-12.5	10.8	-9.4
Wapusk	Hudson Plains	-23.9	-8.3	11.2	-1.8
Waterton Lakes	Montane Cordillera	-6.3	3.0	13.9	4.7
Wood Buffalo	Taiga Plains/Taiga Shield/Boreal Shield/ Boreal Plains	-22.0	-2.4	14.9	-1.4
Yoho	Montane Cordillera	-6.8	6.1	16.5	5.2

Appendix B – Ecodistrict Based* Precipitation Normals (1961-90)

Park	Ecodistrict(s)	Mean Seasonal Precipitation 1961-90 (mm) Winter	Spring	Summer	Fall
Aulavik	Northern Arctic	12.0	15.4	46.2	36.0
Auyuittuq	Arctic Cordillera/ Northern Arctic	27.1	38.6	68.3	91.6
Banff	Montane Cordillera	91.5	104.7	190.4	109.7
Bruce Peninsula	Mixed Wood Plains	221.4	184.3	208.6	256.7
Cape Breton Highlands	Atlantic Maritime	437.8	328.4	286.0	433.6
Elk Island	Prairies	57.6	76.5	230.0	70.6
Quttinirpaaq	Arctic Cordillera/ Northern Arctic	14.4	17.8	47.7	34.7
Forillon	Atlantic Maritime	250.5	238.7	286.3	287.3
Fundy	Atlantic Maritime	362.7	310.8	298.0	353.3
Georgian Bay Islands	Boreal Shield/ Mixed Wood Plains	232.8	204.8	244.3	264.4
Glacier	Montane Cordillera	303.3	166.6	207.4	256.3
Grasslands	Prairies	53.1	98.8	141.5	61.5
Gros Morne	Boreal Shield	326.4	208.4	300.3	329.4
Gwaii Haanas	Pacific Maritime	778.5	523.1	306.9	826.1
Ivvavik	Southern Arctic/ Taiga Cordillera	16.5	15.8	87.8	53.4
Jasper	Boreal Plains/ Montane Cordillera	106.1	100.1	179.4	122.2
Kejimkujik	Atlantic Maritime	409.9	324.5	284.9	363.1
Kluane	Boreal Cordillera/ Pacific Maritime	44.0	42.9	139.6	68.4
Kootenay	Montane Cordillera	119.2	96.4	136.2	103.8
Kouchibouguac	Atlantic Maritime	305.9	265.1	272.2	292.6
La Mauricie	Boreal Shield	207.4	216.0	301.5	265.2
Mingan Archipelago	Boreal Shield	199.0	222.0	284.0	306.2
Mount Revelstoke	Montane Cordillera	309.6	169.6	210.1	261.7
Nahanni	Taiga Plains/ Taiga Cordillera/ Boreal Cordillera	54.3	61.8	159.7	94.2
Pacific Rim	Pacific Maritime	1232.9	682.9	260.7	1002.3
Point Pelee	Mixed Wood Plains	181.3	234.1	254.1	221.5
Prince Albert	Boreal Plains	63.2	89.1	205.6	94.5
Prince Edward Island	Atlantic Maritime	290.4	249.2	248.9	344.5
Pukaskwa	Boreal Shield	176.2	156.6	227.0	214.5
Riding Mountain	Boreal Plains/Prairies	62.1	106.1	219.2	114.1
Saint Lawrence Islands	Mixed Wood Plains	203.7	200.6	222.9	249.4

* - Current climate for each national park derived from a spatially weighted average of each ecodistrict in the park (percent of total park area).

Appendix B - Continued

Park	Ecodistrict(s)	Mean Seasonal Precipitation 1961-90 (mm)			
		Winter	Spring	Summer	Fall
Terra Nova	Boreal Shield	310.6	279.3	263.7	320.3
Tuktut Nogait	Southern Arctic	15.6	21.5	76.6	54.2
Vuntut	Taiga Cordillera	24.2	29.3	96.9	69.0
Wapusk	Hudson Plains	58.6	82.2	184.3	148.3
Waterton Lakes	Montane Cordillera	198.9	225.0	188.6	171.5
Wood Buffalo	Taiga Plains/Taiga Shield/Boreal Shield/ Boreal Plains	55.0	57.5	152.2	95.0
Yoho	Montane Cordillera	167.6	111.0	144.2	135.1

Appendix C – Climate Monitoring Station Nearest National Park Geocentroids

Park	Park Geocentroid Lat.	Park Geocentroid Long.	Nearest Climate Station	Station Lat.	Station Long.
Aulavik	76° 14'	119° 20'	Thomsen River	73°14'	119°32'
Auyuittuq	68° 28'	66° 48'	Cape Hooper	68°28'	66°49'
Banff	51° 11'	115° 34'	Banff	51° 11'	115° 34'
Bruce Peninsula	44° 45'	81° 06'	Tobermory	45°14'	81°32'
Cape Breton Highlands	46°39'	60°57'	Cheticamp	46°39'	60°57'
Elk Island	53°53'	111°4'	Elk Point	53°53'	111°4'
Quttinirpaaq	82° 30'	62° 20'	Lake Hazen	81°49'	71°18'
Forillon	47° 23'	61° 52'	Gaspe	48°50'	64°29'
Fundy	45° 20'	65° 53'	Fundy		
Georgian Bay Islands	44° 58'	79° 18'	Midland Water	44°45'	79°53'
Glacier	51°17'	117°31'	Glacier NP Rogers Pass	51°17'	117°31'
Grasslands	49°6'	107°1'	Mankota	49°6'	107°1'
Gros Morne	49° 13'	57° 24'	Cow Head	49°54'	57°48'
Gwaii Haanas	53° 15'	131° 49'	Ikeda Bay	52°17'	131°7'
Ivvavik	68° 57'	137° 13'	Stokes Point	69°20'	138°46'
Jasper	52° 53'	118° 04'	Jasper	52° 53'	118° 04'
Kejimkujik	44°26'	65°12'	Kejimkujik Park	44°26'	65°12'
Kluane	61° 22'	139° 03'	Kluane Lake	61°1'	138°24'
Kootenay	50°37'	116°4'	Kootnay NP West Gate	50°37'	116°4'
Kouchibouguac	46° 07'	64° 41'	Kouchibouguac		
La Mauricie	45° 31'	73° 25'	Curtiss depot	46°42'	73°1'
Mingan Archipelago	50°17'	62°48'	Baie Johan Beetz	50°17'	62°48'
Mount Revelstoke	50° 58'	118° 11'	Revelstoke A	50° 58'	118° 11'
Nahanni	63° 13'	123° 26'	Nahanni		
Pacific Rim	49° 15'	124° 50'	Bamfield East	48°50'	125°7'
Point Pelee	41°45'	82°41'	Pelee Island		
Prince Albert	53° 13'	105° 41'	Prince Albert A	53° 13'	105° 41'
Prince Edward Island	46° 26'	63° 50'	Stanhope	46°25'	63°5'
Pukaskwa	49° 24'	82° 26'	Pukaskwa		
Riding Mountain	51° 06'	100° 03'	Riding Mountain Park	50°42'	99°41'
Saint Lawrence Islands	43° 13'	76° 36'	Mallorytown Graham Lake	44°34'	75°53'
Terra Nova	48°33'	53°59'	Terra Nova Nat Park HQ	48°33'	53°59'
Tuktut Nogait	69° 35'	120° 48'	Tuktut Nogait		
Vuntut	69° 35'	140° 11'	Sam Lake	68°25'	138°37'
Wapusk	58° 44'	94° 04'	York Factory	57°0'	92°18'
Waterton Lakes	49° 38'	112° 48'	Waterton River Cabin	49°7'	113°50'
Wood Buffalo	58° 46'	111° 07'	Davidson Lake Tower	58°53'	113°13'
Yoho	51° 18'	116° 59'	Yoho NP Boulder CR	51°23'	116°32'

Appendix D – Climate Normals Derived from Nearest Climate Station Data

Park	Nearest Climate Station	Mean Seasonal Temperature 1961-90 (°C) Winter	Spring	Summer	Fall
Aulavik	Thomsen River	-32.9	-22.6	1.7	-17
Auyuittuq	Cape Hooper	-24.4	-16.6	2.3	-8.5
Banff	Banff	-8.3	3	13.7	-14.4
Bruce Peninsula	Tobermory	-6.1	4.2	17.3	8.6
Cape Breton Highlands	Cheticamp	-4.1	3.0	16.7	8.9
Elk Island	Elk Point	-15.4	2.2	15.3	2.2
Quttinirpaaq	Lake Hazen	-31.7	-23.3	1.1	-18.7
Forillon	Gaspe	-5.6	0.63	15	7.8
Fundy	Fundy	-7	3.2	15.8	7.4
Georgian Bay Islands	Midland Water	-9	4	17.2	7.1
Glacier	Glacier NP Rogers Pass	-8.8	1.5	11.8	1.5
Grasslands	Mankota	-12.4	3.6	17.3	3.9
Gros Morne	Cow Head	-7.5	1.1	14.7	5.6
Gwaii Haanas	Ikeda Bay	3.3	6.5	13.5	9.1
Ivvavik	Stokes Point	-26.3	-15.2	8.3	-8.5
Jasper	Jasper	-8.8	3.7	14.2	3.5
Kejimkujik	Kejimkujik Park	-4.7	4.6	17.2	8.3
Kluane	Kluane Lake	-20.1	-2.7	11.1	-4.7
Kootenay	Kootnay NP West Gate	-7.2	6.5	17.0	4.9
Kouchibouguac	Kouchibouguac	-7.5	3.2	17.1	7.3
La Mauricie	Curtiss depot	-8.7	5.3	19.2	7.9
Mingan Archipelago	Baie Johan Beetz	-12.4	-0.1	13.4	6.8
Mount Revelstoke	Revelstoke A	-4.1	7	17.3	6.5
Nahanni	Nahanni	-26.15	-3.9	16.9	-5.3
Pacific Rim	Bamfield East	2.6	8.4	16.5	9.8
Point Pelee	Pelee Island	-3.2	7.7	21.8	12.1
Prince Albert	Prince Albert A	-17.5	1.4	16.3	2
Prince Edward Island	Stanhope	-6.5	2.9	17.4	8.3
Pukaskwa	Pukaskwa	-16.6	-0.1	15.4	3.5
Riding Mountain	Riding Mountain Park	-15.9	1.8	17.3	3.8
Saint Lawrence Islands	Mallorytown Graham Lake	-6.4	5.3	18.8	9
Terra Nova	Terra Nova Nat Park HQ	-5.2	2.0	14.7	6.7
Tuktut Nogait	Tuktut Nogait	-25.4	-15.9	5.9	-7.9
Vuntut	Sam Lake	-24.4	-16.1	5.8	-9.3
Wapusk	York Factory	-25	-10.4	9.7	-2.8
Waterton Lakes	Waterton River Cabin	-6.6	5.3	17.3	6.6
Wood Buffalo	Davidson Lake Tower	-21.4	-1.3	15.1	-0.7
Yoho	Yoho NP Boulder CR	-7.9	5.7	16.2	4.6

Appendix D - Continued

Park	Nearest Climate Station	Mean Seasonal Precipitation 1961-90 (mm) Winter	Spring	Summer	Fall
Aulavik	Thomsen River	11.7	15.0	44.1	34.2
Auyuittuq	Cape Hooper	27.9	54.3	81.9	114.0
Banff	Banff	89.4	111.3	162.6	104.4
Bruce Peninsula	Tobermory	270.6	198.0	231.3	299.4
Cape Breton Highlands	Cheticamp	424.6	288.7	281.2	381.8
Elk Island	Elk Point	60.8	85.9	209.9	79.3
Quttinirpaaq	Lake Hazen	20.4	26.1	61.5	46.2
Forillon	Gaspe	293.4	222.6	198.6	272.7
Fundy	Fundy	398.4	342.6	311.4	380.1
Georgian Bay Islands	Midland Water	257.7	227.1	253.2	315.9
Glacier	Glacier NP Rogers Pass	633.9	274.4	272.6	431.0
Grasslands	Mankota	56.3	94.6	134.9	52.0
Gros Morne	Cow Head	272.7	199.5	263.4	298.8
Gwaii Haanas	Ikeda Bay	462.3	261.6	156.0	479.4
Ivvavik	Stokes Point	20.1	27.6	109.5	73.8
Jasper	Jasper	75.3	65.4	156.6	96.0
Kejimkujik	Kejimkujik Park	421.8	328.9	288.8	358.5
Kluane	Kluane Lake	30.6	48.3	156.3	54.9
Kootenay	Kootnay NP West Gate	99.0	86.5	141.3	87.4
Kouchibouguac	Kouchibouguac	342.3	309.3	276.3	300.9
La Mauricie	Curtiss depot	238.2	227.1	280.5	270.3
Mingan Archipelago	Baie Johan Beetz	159.3	0.0	274.6	299.1
Mount Revelstoke	Revelstoke A	319.8	175.2	199.8	255.3
Nahanni	Nahanni	43.8	59.7	158.7	88.2
Pacific Rim	Bamfield East	809.7	389.7	108.0	578.4
Point Pelee	Pelee Island	170.8	236.3	258.5	225.2
Prince Albert	Prince Albert A	48.0	81.9	197.7	78.0
Prince Edward Island	Stanhope	287.7	245.1	249.9	278.1
Pukaskwa	Pukaskwa	135.9	174.3	277.8	239.1
Riding Mountain	Riding Mountain Park	55.8	110.1	210.0	115.8
Saint Lawrence Islands	Mallorytown Graham Lake	234.3	233.7	218.4	277.5
Terra Nova	Terra Nova Nat Park HQ	315.8	286.8	263.5	318.4
Tuktut Nogait	Tuktut Nogait	14.1	21.0	81.0	53.7
Vuntut	Sam Lake	14.7	11.4	81.0	46.8
Wapusk	York Factory	49.8	71.4	155.7	134.7
Waterton Lakes	Waterton River Cabin	53.4	113.4	154.5	76.5
Wood Buffalo	Davidson Lake Tower	57.3	67.5	156.9	99.9
Yoho	Yoho NP Boulder CR	157.8	77.4	134.4	121.2

Appendix E - Projected Temperature Change from Five GCM Experiments

Park	1961-90 Mean (°C)	WINTER Projected Change (°C) GISS	GDFL	CCC-II	CCC-CI 2050	CCC-CI 2090
Aulavik	-32.3	11	6	7	5	11
Auyuittuq	-26.3	3	7	10	5	10
Banff	-8.5	3	2	6	4	6
Bruce Peninsula	-6.7	2	4	7	5	6
Cape Breton Highlands	-4.1	3	5	4	2	3
Elk Island	-12.4	2	3	5	5	9
Quttinirpaaq	-33.8	6	5	7	6	11
Forillon	-10.0	3	5	7	2	4
Fundy	-6.3	3	5	5	2	4
Georgian Bay Islands	-8.8	2	4	7	5	6
Glacier	-6.4	3	2	5	3	5
Grasslands	-11.6	3	3	8	5	8
Gros Morne	-6.7	3	4	7	2	4
Gwaii Haanas	3.6	2	3	3	2	4
Ivvavik	-24.7	6	4	4	6	9
Jasper	-8.2	2	2	5	3	5
Kejimkujik	-4.4	3	4	4	2	3
Kluane	-20.0	2	2	4	4	8
Kootenay	-6.8	3	2	5	3	5
Kouchibouguac	-8.4	3	5	5	2	4
La Mauricie	-12.2	2	5	5	3	5
Mingan Archipelago	-11.4	2	5	7	2	4
Mount Revelstoke	-6.4	3	2	5	3	5
Nahanni	-25.3	3	3	6	5	8
Pacific Rim	4.2	3	2	4	2	4
Point Pelee	-3.4	1	4	7	5	7
Prince Albert	-16.7	3	3	8	5	9
Prince Edward Island	-5.8	2	5	5	2	4
Pukaskwa	-13.6	2	4	7	5	7
Riding Mountain	-16.4	2	3	8	5	10
Saint Lawrence Islands	-7.2	2	4	5	3	5
Terra Nova	-5.4	2	4	5	2	4
Tuktut Nogait	-26.1	7	4	6	4	8
Vuntut	-28.1	6	4	4	6	9
Wapusk	-23.9	4	4	8	8	12
Waterton Lakes	-6.3	3	3	6	4	6
Wood Buffalo	-22.0	3	5	6	5	9
Yoho	-6.8	3	2	5	3	5

Appendix E - Continued

Park	1961-90 Mean (°C)	SPRING Projected Change (°C) GISS	GDFL	CCC-II	CCC-CI 2050	CCC-CI 2090
Aulavik	-22.0	5	6	4	4	9
Auyuittuq	-17.9	3	3	4	3	10
Banff	3.0	2	3	6	5	6
Bruce Peninsula	3.5	1	3	6	3	7
Cape Breton Highlands	2.8	3	3	4	2	3
Elk Island	3.4	2	2	5	5	8
Quttinirpaaq	-24.1	5	5	5	4	8
Forillon	1.1	2	3	4	2	4
Fundy	3.7	2	3	4	2	5
Georgian Bay Islands	4.2	1	3	6	3	7
Glacier	5.2	2	3	5	3	5
Grasslands	3.8	1	2	8	6	7
Gros Morne	0.8	2	3	4	2	4
Gwaii Haanas	6.5	2	2	3	2	4
Ivvavik	-15.7	4	4	6	4	9
Jasper	3.6	2	3	5	3	5
Kejimkujik	4.6	2	3	4	2	5
Kluane	-2.3	2	2	4	3	7
Kootenay	6.4	2	3	5	3	5
Kouchibouguac	2.4	1	3	4	2	5
La Mauricie	2.9	1	3	4	2	6
Mingan Archipelago	-0.1	2	3	4	2	4
Mount Revelstoke	5.1	2	3	5	3	5
Nahanni	-3.6	2	4	4	3	4
Pacific Rim	8.0	2	2	4	2	4
Point Pelee	7.7	1	3	8	4	8
Prince Albert	1.0	1	3	5	5	6
Prince Edward Island	2.5	3	3	4	3	5
Pukaskwa	0.4	1	3	4	2	6
Riding Mountain	1.4	2	3	8	6	9
Saint Lawrence Islands	6.0	1	3	5	3	6
Terra Nova	1.7	2	3	4	2	4
Tuktut Nogait	-16.4	4	5	4	4	7
Vuntut	-12.5	4	4	6	4	9
Wapusk	-8.3	2	4	4	5	9
Waterton Lakes	3.0	2	3	6	5	6
Wood Buffalo	-2.4	1	5	3	3	4
Yoho	6.1	2	3	5	3	5

Appendix E - Continued

Park	1961-90 Mean (°C)	SUMMER				
		Projected Change (C)				
		GISS	GDFL	CCC-II	CCC-CI 2050	CCC-CI 2090
Aulavik	2.1	2	1	5	5	9
Auyuittuq	2.9	2	1	3	3	6
Banff	13.6	1	2	4	3	4
Bruce Peninsula	16.8	1	4	5	2	5
Cape Breton Highlands	16.7	2	3	4	1	2
Elk Island	15.9	1	2	3	2	4
Quttinirpaaq	2.2	1	1	7	4	9
Forillon	15.2	2	3	3	2	4
Fundy	16.2	2	3	4	2	5
Georgian Bay Islands	17.7	1	4	5	2	5
Glacier	15.6	1	2	3	3	4
Grasslands	17.5	1	3	5	3	5
Gros Morne	13.9	2	3	4	2	4
Gwaii Haanas	13.0	2	2	4	2	4
Ivvavik	6.6	3	2	5	4	7
Jasper	14.0	2	2	3	2	4
Kejimkujik	17.3	2	3	4	2	4
Kluane	11.3	3	3	6	4	7
Kootenay	16.7	1	2	3	3	4
Kouchibouguac	16.9	2	3	4	2	5
La Mauricie	17.2	2	3	4	2	5
Mingan Archipelago	13.2	2	2	3	2	4
Mount Revelstoke	15.5	1	2	3	3	4
Nahanni	14.6	2	2	4	3	5
Pacific Rim	14.4	2	2	3	2	4
Point Pelee	21.3	1	4	5	3	5
Prince Albert	15.2	1	2	4	3	5
Prince Edward Island	16.9	2	3	4	2	5
Pukaskwa	12.8	1	3	4	3	5
Riding Mountain	16.5	1	2	6	4	6
Saint Lawrence Islands	19.5	1	4	5	2	5
Terra Nova	14.3	2	3	4	2	5
Tuktut Nogait	5.6	2	2	5	4	7
Vuntut	10.8	3	2	5	4	7
Wapusk	11.2	0	3	5	4	7
Waterton Lakes	13.9	1	3	4	3	4
Wood Buffalo	14.9	0	2	3	3	5
Yoho	16.5	1	2	3	3	4

Appendix E - Continued

Park	1961-90 Mean (°C)	FALL Projected Change (C) GISS	GDFL	CCC-II	CCC-CI 2050	CCC-CI 2090
Aulavik	-16.2	7	6	8	4	8
Auyuittuq	-8.3	2	4	4	2	4
Banff	3.2	2	3	3	2	4
Bruce Peninsula	8.5	2	3	3	2	5
Cape Breton Highlands	8.8	2	3	4	2	3
Elk Island	3.3	2	4	3	2	4
Quttinirpaaq	-19.3	4	6	8	8	11
Forillon	5.3	2	3	3	2	4
Fundy	7.9	2	3	4	2	4
Georgian Bay Islands	7.4	2	3	3	2	5
Glacier	4.9	2	3	3	2	4
Grasslands	4.2	2	4	3	2	4
Gros Morne	6.1	2	4	3	2	4
Gwaii Haanas	9.2	3	2	3	2	4
Ivvavik	-9.1	4	5	5	3	7
Jasper	3.5	2	3	3	2	4
Kejimkujik	8.6	2	3	4	2	4
Kluane	-3.5	2	3	4	2	4
Kootenay	5.3	2	3	3	2	4
Kouchibouguac	6.9	2	3	4	2	4
La Mauricie	5.7	2	3	3	2	4
Mingan Archipelago	3.9	2	3	3	2	4
Mount Revelstoke	4.9	2	3	3	2	4
Nahanni	-5.1	3	3	3	1	3
Pacific Rim	9.9	2	3	3	2	4
Point Pelee	11.5	1	3	3	2	5
Prince Albert	1.8	2	4	3	2	4
Prince Edward Island	8.5	2	3	3	2	4
Pukaskwa	5.1	2	3	3	2	4
Riding Mountain	2.9	2	4	4	3	4
Saint Lawrence Islands	8.9	2	3	3	2	4
Terra Nova	6.6	2	4	3	2	4
Tuktut Nogait	-8.0	4	6	6	2	6
Vuntut	-9.4	4	5	5	3	7
Wapusk	-1.8	3	4	3	2	5
Waterton Lakes	4.7	2	3	3	2	4
Wood Buffalo	-1.4	2	6	3	1	3
Yoho	5.2	2	3	3	2	4

Appendix F - Projected Precipitation Change from Five GCM Experiments

Park	1961-90 Mean (°C)	WINTER Projected Change (C) GISS	GDFL	CCC-II	CCC-CI 2050	CCC-CI 2090
Aulavik	11.7	37	3	-3	-18	-7
Auyuittuq	27.9	5	21	13	-4	0
Banff	89.4	10	10	33	2	5
Bruce Peninsula	270.6	3	17	1	-2	6
Cape Breton Highlands	424.6	14	24	5	4	3
Elk Island	60.8	23	4	29	8	15
Quttinirpaaq	20.4	20	20	2	23	10
Forillon	293.4	24	24	1	-3	10
Fundy	398.4	19	11	7	9	4
Georgian Bay Islands	257.7	9	17	1	-2	6
Glacier	633.9	6	10	25	5	9
Grasslands	56.3	26	11	15	15	20
Gros Morne	272.7	14	16	5	-2	11
Gwaii Haanas	462.3	5	-1	27	5	20
Ivvavik	20.1	33	6	6	-3	2
Jasper	75.3	2	10	25	7	15
Kejimkujik	421.8	19	-3	11	7	-4
Kluane	30.6	9	25	13	-1	11
Kootenay	99.0	10	10	24	2	5
Kouchibouguac	342.3	23	24	7	9	4
La Mauricie	238.2	24	28	6	6	1
Mingan Archipelago	159.3	18	24	2	-1	10
Mount Revelstoke	319.8	6	10	25	5	9
Nahanni	43.8	10	16	33	24	40
Pacific Rim	809.7	3	5	34	14	28
Point Pelee	170.8	4	12	-4	-1	20
Prince Albert	48.0	18	3	35	-1	16
Prince Edward Island	287.7	15	11	9	9	1
Pukaskwa	135.9	5	25	12	10	9
Riding Mountain	55.8	14	10	-9	-8	-13
Saint Lawrence Islands	234.3	14	15	8	10	5
Terra Nova	315.8	10	16	8	7	10
Tuktut Nogait	14.1	25	0	9	-24	-10
Vuntut	14.7	33	6	6	-3	2
Wapusk	49.8	8	4	30	16	11
Waterton Lakes	53.4	10	11	33	2	5
Wood Buffalo	57.3	3	14	3	-11	6
Yoho	157.8	10	10	24	2	5

Appendix F - Continued

Park	1961-90 Mean (°C)	SPRING Projected Change (C) GISS	GDFL	CCC-II	CCC-CI 2050	CCC-CI 2090
Aulavik	15.0	-8	17	-13	6	-8
Auyuittuq	54.3	10	-7	29	-3	20
Banff	111.3	10	3	19	5	20
Bruce Peninsula	198.0	6	24	10	10	27
Cape Breton Highlands	288.7	19	19	-2	9	11
Elk Island	85.9	2	15	29	15	34
Quttinirpaaq	26.1	-14	0	-10	-10	0
Forillon	222.6	12	23	3	9	1
Fundy	342.6	19	12	1	1	17
Georgian Bay Islands	227.1	6	24	10	10	27
Glacier	274.4	9	3	-1	-4	4
Grasslands	94.6	1	11	41	36	59
Gros Morne	199.5	10	20	-1	15	9
Gwaii Haanas	261.6	4	5	-1	3	-6
Ivvavik	27.6	11	14	8	-4	-7
Jasper	65.4	5	3	13	3	10
Kejimkujik	328.9	19	5	1	0	6
Kluane	48.3	4	11	7	8	2
Kootenay	86.5	10	3	4	1	11
Kouchibouguac	309.3	16	19	1	1	17
La Mauricie	227.1	9	19	8	4	15
Mingan Archipelago	0.0	13	27	2	9	4
Mount Revelstoke	175.2	9	3	-1	-4	4
Nahanni	59.7	15	13	5	28	26
Pacific Rim	389.7	2	3	-9	-8	-11
Point Pelee	236.3	9	17	7	27	34
Prince Albert	81.9	24	10	28	16	21
Prince Edward Island	245.1	21	12	4	2	19
Pukaskwa	174.3	2	19	27	16	39
Riding Mountain	110.1	10	19	26	4	11
Saint Lawrence Islands	233.7	6	20	3	10	11
Terra Nova	286.8	11	20	2	11	11
Tuktut Nogait	21.0	-5	19	1	16	-12
Vuntut	11.4	11	14	8	-4	-7
Wapusk	71.4	-1	10	22	14	9
Waterton Lakes	113.4	10	7	19	5	20
Wood Buffalo	67.5	31	13	2	10	4
Yoho	77.4	10	3	4	1	11

Appendix F - Continued

Park	1961-90 Mean (°C)	SUMMER Projected Change (C) GISS	GDFL	CCC-II	CCC-CI 2050	CCC-CI 2090
Aulavik	44.1	-8	31	44	10	44
Auyuittuq	81.9	17	21	28	-4	29
Banff	162.6	-3	-13	-1	-5	-1
Bruce Peninsula	231.3	6	-14	1	-8	-13
Cape Breton Highlands	281.2	-26	7	-9	1	3
Elk Island	209.9	17	-11	-5	4	7
Quttinirpaaq	61.5	-4	10	6	20	24
Forillon	198.6	-12	5	-7	2	7
Fundy	311.4	-19	12	-10	-10	0
Georgian Bay Islands	253.2	2	-14	1	-8	-13
Glacier	272.6	-5	-13	-3	-6	-3
Grasslands	134.9	-7	-14	-6	-34	-26
Gros Morne	263.4	-9	3	-1	15	33
Gwaii Haanas	156.0	2	-6	9	0	-3
Ivvavik	109.5	23	12	28	25	30
Jasper	156.6	7	-13	-5	-1	2
Kejimkujik	288.8	-19	16	-10	-5	-2
Kluane	156.3	10	22	11	0	-5
Kootenay	141.3	-3	-13	2	-7	-4
Kouchibouguac	276.3	-9	7	-10	-10	0
La Mauricie	280.5	-5	-4	10	-7	-4
Mingan Archipelago	274.6	-17	3	-5	-1	10
Mount Revelstoke	199.8	-5	-13	-3	-6	-3
Nahanni	158.7	11	-12	20	51	95
Pacific Rim	108.0	-2	-32	-8	0	0
Point Pelee	258.5	-10	-8	-2	7	-4
Prince Albert	197.7	16	-1	-10	-10	-5
Prince Edward Island	249.9	-29	12	-10	-7	0
Pukaskwa	277.8	5	5	2	-3	-2
Riding Mountain	210.0	-5	18	-13	-29	-19
Saint Lawrence Islands	218.4	-3	-18	5	-7	-7
Terra Nova	263.5	-11	3	7	-3	15
Tuktut Nogait	81.0	15	8	20	0	22
Vuntut	81.0	23	12	28	25	30
Wapusk	155.7	39	6	14	9	12
Waterton Lakes	154.5	-3	-11	-1	-5	-2
Wood Buffalo	156.9	23	16	-8	-6	14
Yoho	134.4	-3	-13	2	-7	-4

Appendix F - Continued

Park	1961-90 Mean (°C)	FALL Projected Change (C) GISS	GDFL	CCC-II	CCC-CI 2050	CCC-CI 2090
Aulavik	34.2	23	11	12	9	3
Auyuittuq	114.0	4	20	29	6	24
Banff	104.4	7	-1	13	12	37
Bruce Peninsula	299.4	2	-2	-23	7	6
Cape Breton Highlands	381.8	7	13	0	2	2
Elk Island	79.3	3	-10	36	9	15
Quttinirpaaq	46.2	23	10	12	12	12
Forillon	272.7	8	13	-3	5	-2
Fundy	380.1	2	12	1	-9	-4
Georgian Bay Islands	315.9	2	-2	-23	7	-6
Glacier	431.0	8	-1	25	13	36
Grasslands	52.0	-16	-9	-1	2	17
Gros Morne	298.8	3	18	11	11	8
Gwaii Haanas	479.4	19	-7	13	-4	3
Ivvavik	73.8	9	13	4	6	10
Jasper	96.0	15	-1	28	12	27
Kejimkujik	358.5	2	10	-4	-12	-3
Kluane	54.9	8	8	23	2	-4
Kootenay	87.4	7	-1	23	15	39
Kouchibouguac	300.9	-1	13	1	-9	-4
La Mauricie	270.3	-2	9	-4	-8	-6
Mingan Archipelago	299.1	10	13	2	6	2
Mount Revelstoke	255.3	8	-1	25	13	36
Nahanni	88.2	10	12	11	58	75
Pacific Rim	578.4	15	-7	32	5	18
Point Pelee	225.2	3	-9	-36	27	39
Prince Albert	78.0	8	-9	22	9	13
Prince Edward Island	278.1	4	12	2	-7	-4
Pukaskwa	239.1	0	-9	1	0	26
Riding Mountain	115.8	-7	2	24	18	17
Saint Lawrence Islands	277.5	1	5	-11	-7	-3
Terra Nova	318.4	6	18	11	10	15
Tuktut Nogait	53.7	18	7	26	8	10
Vuntut	46.8	9	13	4	6	10
Wapusk	134.7	8	2	16	12	22
Waterton Lakes	76.5	7	-3	13	12	39
Wood Buffalo	99.9	7	13	27	18	31
Yoho	121.2	7	-1	23	15	39

Appendix G - Impact Assessment Checklist

CLIMATOLOGY	temperature	**GEOMORPHOLOGY**	
	precipitation	Periglacial	polygons
	humidity		thermokarst
	windchill		ground ice
	cloud cover		permafrost
	fog		solifluction
	solar radiation		frost heave
	wind	Weathering	soil
	inversions		karst
	extreme events	Erosional	river valleys
HYDROLOGY			coastal cliffs
Snow & Glaciers	glacial winds		mud flows
	deposition		soil creeps
	erosion		landslides
	sediment transport		debris flow
	abrasion	Depositional	beaches
	albedo		deltas
	spring thaw		river floodplains
	mass balance		moraines
	avalanches		dunes
	snow depth	**BIOLOGY**	
Groundwater	potable water	**PLANTS**	
	recharge	Migration	biome shift
	wetlands		habitat ratio
Oceans, Lakes, Rivers	sea ice		latitude
	water level change		elevational
	sediment transport		barriers
	erosion		extinction
	river course		invasive species
	speed		diversity
	pollution	Disturbance	fire
	eutroph.		drought
	deposition, deltas		insects
	intertidal		disease
	limnology		extreme events
	salinity	**WILDLIFE**	
		Migration	habitat range
CULTURAL	tourist season		barriers
	visitor experience		generalists
	visitor safety		resilience
	activity seasons	Reproduction	timing
	infrastructure risk	Disturbance	fire
	archeology		drought
	cultural resources		insects
			extreme events

Appendix H - Species List: Common and Latin Names

Common Name	Scientific Name
PLANTS	
American elm	*Ulmus americana*
ash	*Fraxinus spp.*
aspen	*Populus spp.*
baked apple	*Rubus chamaemorus*
balsam fir	*Abies balsamia*
balsam poplar	*Populus balsamifera*
beech bark fungus	*Nectria coccinea*
birch	*Betula spp.*
black crowberry	*Empetrum nigrum*
black spruce	*Picea mariana*
blood-root	*Sanguinaria canadensis*
bog laurel	*Kalmia polifolia*
cheatgrass	*Bromus tectorum*
cottongrass	*Eriophorum spp.*
deerberry	*Vaccineum stamineum*
Douglas fir	*Pseudotsuga menziesii*
dutchman's breeches	*Dicentra cucu llaria*
eastern larch (tamarack)	*Larix laricina*
eel grass	*Zostera marina*
elm	*Ulmus spp.*
false heather	*Hudsonia tomentosa*
hickory	*Carya spp.*
hemlock	*Tsuga spp.*
Jack pine	*Pinus banksiana*
	Pinus divaricata
knapweed	*Centaurea spp.*
Labrador tea	*Ledum groenlandicum*
leatherleaf	*Chamaedaphne calyculata*
lodgepole pine	*Pinus contorta*
marram grass	*Ammophila maritima*
mingan thistle	*Cirsium minganense*
oak	*Quercus spp.*
pitch pine	*Pinus rigida*
pitcher plant	*Sarracenia purpurea*
ponderosa pine	*Pinus ponderosa*
red maple	*Acer rubrum*
red oak	*Quercus rubra*
red pine	*Pinus resinosa*
red spruce	*Picea rubens*
reindeer moss	*Cladina spp.*
rue anemone	*Anemonella thalictroides*
Russian thistle	*Salsola kali*
sedges	*Carex spp.*

Appendix H - Continued

Common Name	*Scientific Name*
sugar maple	*Acer sachharum*
sundew	*Drosera spp.*
tufted club rush	*Scirpus cespitosus*
western cedar	*Thuja plicata*
western hemlock	*Tsuga heterophylla*
western larch	*Larix occidentialis*
wheatgrass	*Elytrigia spp.*
white birch	*Betula papyrifera*
white pine	*Pinus alba*
white spruce	*Picea glauca*
white trillium	*Trillium grandiflorum*
willow	*Salix spp.*
MAMMALS	
Arctic hare	*Lepus arcticus*
Arctic fox	*Alopex lagopus*
Arctic wolf	*Canis lupus mackenzii*
big horn sheep	*Ovis canadensis*
black bear	*Ursus americanus*
black tailed deer	*Odocoileus hermionus columbianus*
brown lemming	*Lemmus trimucronatus*
barren-ground caribou	*Rangifer tarandus groenlandicus*
collared lemming	*Dicrostomyx groenlandicus*
Dall's sheep	*Ovis dalli*
elk	*Cervus canadensis*
	Cervus elaphus
gray seal	*Halichoerus grypus*
gray whale	*Eschrichtius glaucus*
grizzly bears	*Ursus horribilis*
harbour seal	*Phoca vitulina*
hoary marmot	*Marmota caligata*
moose	*Alces alces*
mountain goat	*Oreamnos americanus*
mule deer	*Dama hemionus*
muskox	*Ovibos moschatus*
muskrat	*Ondatra zibethicus*
Peary caribou	*Rangifer tarandus pearyi*
polar bear	*Ursus maritimus*
raccoon	*Procyon lotor vancouverensis*
rat	*Rattus norvigicus*
ringed seals	*Phoca hispida*
timber wolf	*Canis lupus*
walrus	Odobenus *rosmarus*
white tailed deer	*Dama virginiana*
wolverine	*Gulo luscus*
wood bison	*Bison bison athabascae*
woodland caribou	*Rangifer tarandus caribou*

Appendix H - Continued

Common Name	*Scientific Name*
BIRDS	
Arctic tern	*Sterna paradisaea*
Atlantic puffin	*Fratercula arctica*
black brant	*Branta bernicla nigricans*
black-legged kittiwake	*Rissa tridactyla*
Cassin's auklet	*Ptychoramphus aleutica*
common eider	*Somateria mollissima*
common murre	*Vria aalge*
common tern	*Sterna hirundo hirundo*
great black-backed gulls	*Larus marinus*
gulls	*Larus spp.*
herring gull	*Larus argentatus*
mew gull	*Larus canus*
northern gannet	*Sula bassanus*
osprey	*Pandion haliaetus*
pelagic cormorant	*Phalacrocorax pelagicus*
peregrine falcon	*Falco peregrinus*
piping plover	*Charadrius melodus*
razor-billed auk (razorbill)	*Alca torda*
snow goose	*Anser caerulescens*
thick-billed murre	*Uria lomvia*
trumpeter swan	*Olor buccinator*
tufted puffin	*Lundha cirrhata*
tundra peregrine falcon	*Falco peregrinus tundrius*
white-tailed ptarmigan	*Lagopus leucurus*
whooping crane	*Grus americana*
FISH	
albacore tuna	*Thunnus alalunga*
Arctic char	*Salvelinus alpinus*
Arctic grayling	*Thymallus arcticus*
Atlantic salmon	*Salmo salar*
black bass	*Micropterus salmoides*
brook trout	*Salvelinus fontinalis*
brown bullhead	*Ictalurus nebulosus*
common shiner	*Nctropis cornutus*
fathead minnow	*Pimephales promelas*
gaspereau (alewife)	*Alosa psuedoharengus*
lake trout	*Salvelinus namaycush*
least cisco	*Coregonus sardinella*
longnose sucker	*Catostomus catostomus*
mackerel	*Scomber scombrus*
slimy sculpin	*Cottus cognatus*
smelt	*Osmerus mordax*
striped bass	*Morone saxitalis*
sunfish	*Ennaecanthus spp.*
walleye	*Stizostedion vitreum*
white bass	*Morone chrysops*
white perch	*Morone americana*
yellow perch	*Perca flavescens*

Common Name	Scientific Name
HERPTILES	
black rat snake	*Elaphe elaphe*
Blandings turtle	*Emydoidea blandingi*
Wood turtle	*Clemmys insculpta*
INSECTS	
balsam woolly adelgid	*Adelges piceae*
beach bark disease	*Nectria coccinea*
mountain pine beetle	*Dendroctonus ponderosae*